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AGATHON ALLOY STEELS

THE average motor car owner little understands or appreciates the tremendous stresses and strains to which the vital parts of his car are subjected while speeding over country roads—up hill and down vale. He has little conception of the grating, grinding, wearing effect of steel upon steel that takes place in axle housing, transmission case and under the hood of his car.

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THE BUSINESS OUTLOOK

THE business depression which has been so persistently with us for the past two years has been improving very decidedly within the last few months. In industry and commerce the prevailing sentiment of cautious hopefulness is rapidly changing to one of full-hearted optimism which is the fore-runner of prosperity.

This attitude is being clearly reflected in the advancing prices on the stock markets and the very marked increase in the volume of business which is being transacted throughout the country. As evidenced by the current trade reports, there are long lists of industries which report increased prices on their goods and predict still further increases.

The business cycle through which we are passing will have its reward for those who display enterprise and practice caution. It is, however, appropriate for those engaged in manufacturing or commercial enterprises, that they keep in mind the lessons which were learned back in the days of 1919 and 1920 and profit thereby.

Numerous phases of industry are showing very marked improvement, among which the agricultural industry, the building construction industry, the railroad equipment industry, the oil and petroleum industry, and the iron and steel industry are rapidly approaching a point where it is necessary for them to revise their production schedules in order to supply the demand for their products. This increasing demand likewise brings about increased prices and this is exactly the condition today, prices have been increased and predictions are that there will be further advances.

The iron and steel industry has a greater demand upon its present output than can be supplied by this output. The industry as a whole is working at about 90 per cent of its capacity, and a further increase in production may be difficult due to labor shortage.

Automotive manufacturers are increasing their production schedules, the agricultural implements industry are experiencing rapidly advancing sales and the building construction industry program, including heavy construction work on large structures, is far greater than it was last year, which in turn makes a greater demand upon the steel industry's output.

The pig iron production of the country is rapidly increasing and showed a production for the month of February of better than 90 per cent of the peak output during the World War.

The business outlook for the coming years is particularly bright and the all-important feature of this new prosperity is that quality and service must be paramount.

WINTER SECTIONAL MEETING WELL ATTENDED

THE winter sectional meeting of the society held in Chicago on February 8 and 9 proved to be a decided success as evidenced by the number of members in attendance and the quality of the papers presented.

The meetings were held in the City club. Registration began at 10 a. m. Thursday morning and continued until luncheon was served at noon. The first technical meeting was opened at 2:30 p. m. by Harold F. Wood, metallurgist, with the Wyman-Gordon Co., Ingalls Shepard division, Harvey, Ill. After expressing words of welcome on the behalf of the Chicago chapter of the society to the visiting members, who came from all parts of the country, he turned the meeting over to J. Fletcher Harper, metallurgist with the Allis-Chalmers Co., who presided during the technical paper session. During this afternoon session three papers were read. The first one, "Characteristics of Air Cooling Curves" was presented by E. J. Janitzky, metallurgist with the Illinois Steel Co. Mr. Janitzky's paper was published in the December, 1922, issue of TRANSACTIONS, and as a result a valuable discussion followed the reading of this paper.

The second paper was presented by Robert G. Guthrie, metallurgist with the Peoples Gas Light & Coke Co. of Chicago, dealing with the subject of light. This paper specifically discussed incident, monochromatic and polarized light as used in making microscopic examinations and photomicrographs of metals. The author illustrated his paper with stereopticon slides which brought out the salient points of the paper. One photomicrograph which was exhibited was taken at 11,000 diameters magnification and enlargement.

The third and last paper of the afternoon session was presented by E. E. Thum, associate editor of *Chemical and Metallurgical Engineering*, New York, entitled "Educating the Metallurgist and the Management." This paper was a very capable presentation which developed the author's ideas on the necessity of metallurgists in general to show their respective managements that their departments are not items of over-head and a liability but instead that they are an asset and an earning department. Suggestions as to how this proof could be successfully established were developed in this paper.

At 6:30 p. m. a dinner was served to over 250 members and guests. Following the dinner the toastmaster, H. F. Wood, called upon a number of the directors of the society for their remarks.

Only one technical paper was scheduled for the evening meeting and this was presented by Howard Scott, associate physicist of the Bureau of Standards, Washington, entitled "The Effect of High Temperature Quenching on the Microstructure of High-Carbon Steels." This paper was well illustrated with stereopticon slides showing photomicrographs of typical structures obtained in this investigation. Mr. Scott's paper appears in this issue of TRANSACTIONS.

On Friday, Feb. 9 the board of directors of the society held a meeting at which time a general business session was carried through.

Three plant inspection trips were scheduled for the day. Members assembled at the City club at 10:00 a. m. and were divided into parties, one party going to the Ingalls-Shepard division of the Wyman-Gordon Co., Harvey, Illinois, the second to the Interstate Iron & Steel Co., and the third to the Illinois Steel Co. Approximately one hundred members took advantage of these inspection trips.

THE EFFECT OF HIGH-TEMPERATURE QUENCHING ON THE
MICROSTRUCTURE OF HIGH-CARBON STEELS

By Howard Scott

Abstract

The first sections of this paper deal with the conditions necessary to produce austenite at ordinary temperatures in a plain high-carbon steel and some metallographic properties of this constituent. In contradiction to current views, it is shown that austenite can be obtained with a very slow rate of cooling compared with that necessary to produce martensite in lower carbon steels provided that something over 1.5 per cent carbon is dissolved. This was accomplished by heating a 1.78 per cent carbon steel to nearly 1100 degrees Cent. The transformations in cooling steel are next considered with particular attention directed to the effect of the rate of cooling and thermal stress on the distribution of martensite and troostite. It is shown that the periphery of cylinders during quenching is under tensional stress and this condition is favorable to the precipitation of troostite. Finally several significant aspects of the transformation of austenite to martensite are discussed.

Introduction

IT IS often possible by means of the examination of extreme cases to secure enlightenment on complex phenomena whose crucial features are vague or weakly defined under normal conditions. Such a possibility is presented in the hardening of high-carbon steels. The structure of these steels when quenched in the approved manner reveals little of significance, but when quenched from very high temperatures it is coarser and shows striking characteristics. Furthermore, if the steel contains sufficient carbon, the resulting product may be austenite and the problem is thereby simplified by the elimination of a complicating change, martensite formation, which may be caused to occur subsequently. In view of these possibilities a study was made of the structural changes accompanying the high-temperature hardening and subsequent treatments of three plain high-carbon steels.

This field of investigation is not new, but is only partially developed. Osmond's book, first published in 1904 and translated by Stead (1)*, gives photographs of austenitic carbon steel and of the surface change produced by immersion in liquid air. Hanemann (2) has conducted the most complete microscopic investigation of this type of steel. He notes certain effects of tempering and describes the cementite needles found in an austenitic matrix, which he confuses with other acicular structures. Benedicks (3) and Maurer (4) have also contributed some information on this subject, the work of the latter author being particularly valuable as it is the only source of data on the physical properties of austenitic carbon steel. Scott and Movius (5) have noted significant facts revealed by heating curves of such steel. However, none of these authors appear to have recognized the considerable

*The figures appearing in parentheses following the names of authors, refer to bibliography appended to this paper.

A paper presented before the Chicago sectional meeting of the society, February 8, 1923. The author, Howard Scott, is associate physicist of the Bureau of Standards, Washington, D. C.

difference existing between the structure near the surface and that of the interior.

The work originally planned involved only a study of the effect of several variables on the microstructure of a carbon steel of 1.78 per cent carbon content, but the novelty of the results in this line suggested the desirability of similar experiments on lower carbon steels. These later experiments were concerned primarily with the distribution of martensite and troostite under various hardening conditions, an important, but almost totally neglected, field for investigation.

Experimental Procedure

The compositions of the steels investigated are given in Table I. The A steel was in the form of $\frac{5}{8}$ -inch hexagonal bar, the B and C steels $\frac{1}{2}$ -inch round bars and the D steel $1 \times \frac{3}{4}$ -inch cast bar. The A steel was annealed in the laboratory to facilitate cutting. All specimens were $\frac{1}{2}$ inch in diameter and 1 inch long unless otherwise noted. Heat treatments at temperatures above 300 degrees Cent. were conducted in an electric muffle furnace, no precautions being taken to avoid oxidation. The specimens heated for quenching were held 10 minutes after they came to a color matching the

Table I
Chemical Composition of Steels Investigated

Mark	C per cent	Mn per cent	Si per cent	Sul per cent	Phos per cent	Condition
A*	1.78	0.20	0.09	—	—	As forged and annealed
B	1.16	0.21	0.17	0.010	0.013	Mill annealed
C	1.04	0.25	0.38	0.013	0.018	Hot rolled
D	1.15	12.0	0.55	0.015	0.062	As cast

*The author is indebted to R. P. DeVries, metallurgist of the Ludlum Steel Company for this steel and its analysis.

pyrometer tube. Quenching consisted of dipping the specimen well below the surface of the quenching medium, holding it still until black, and then stirring until cold, the object being to compensate for the slower cooling as the specimen approached the bath temperature. For tempering, the specimen was maintained at the temperature selected, plus or minus 10 degrees Cent., for $\frac{1}{2}$ hour and cooled in air. When the temperature required was under 300 degrees Cent. an oil bath was used. After treatment the specimens were cut in half transversely with a wet flexible cutting disc and one of the new surfaces used for examination. They were etched in 10 per cent picric acid in methanol, unless stated otherwise. The micrographs were taken at a magnification of 500 diameters and the macrographs at 4 diameters with vertical illumination. A slight reduction has been made in reproducing the photographs. The exact magnification is given in each caption.

Constitution of the Austenitic Carbon Steel

The steels investigated may be broadly classified as austenitic and martensitic according to whether they are susceptible of being maintained completely austenitic to ordinary temperatures or not. The former steels are the 1.78 per cent carbon steel A and the Hadfield manganese steel D while the latter are the 1.16 and 1.04 per cent carbon steels B and C. The justification for this classification will appear in the experimental data.

Microstructure

In considering the austenitic carbon steel the first variable to study is

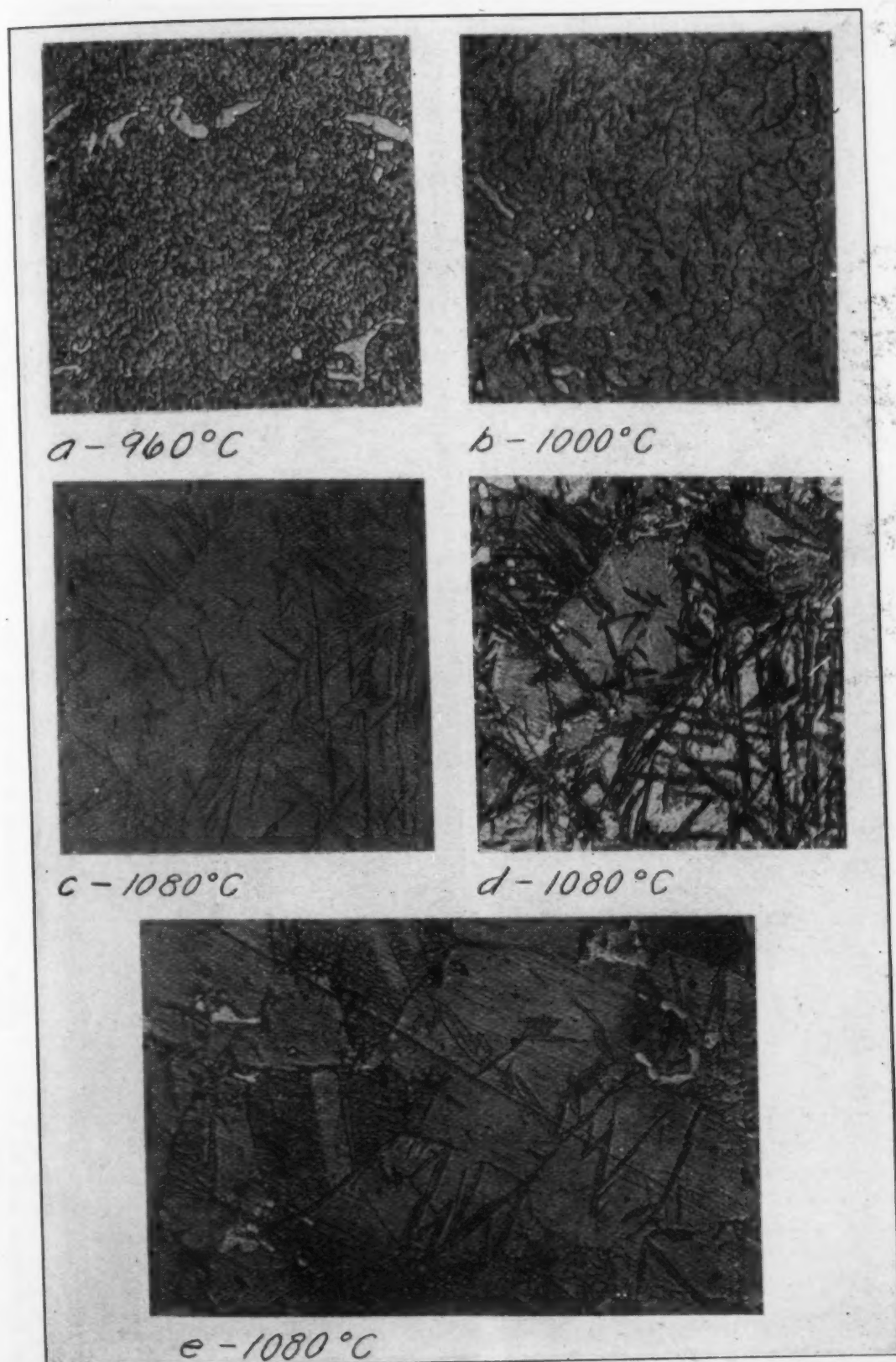


Fig. 1.—Steel A quenched in water from the temperatures indicated. (a), (b) and (c), characteristic structures of the interior; (d) same area as (c) etched longer; (e) area near edge. X 450.



Fig. 2—Structure near the surface of steel A after quenching in water from 1080 degrees Cent.; upper left edge of micrograph shows the surface of metal while upper right and lower left edges are coincident, the photograph being continuous

obviously the quenching temperature. In this steel the cementite is not completely dissolved below the eutectic temperature, that is, the amount of dissolved carbon varies continuously with the temperature from 730 degrees Cent. to something over 1100 degrees Cent. The effect of this variable is shown in Fig. 1. With the lower quenching temperatures, (a) and (b), the structure is characteristic of the normal hardening of high-carbon steels, but an increase in quenching temperature to 1080 degrees Cent., hereafter called the high-temperature, produces a distinctive modification. In the interior of the specimen (c) a structureless matrix is found broken up by grain envelopes and long feathery needles. Deeper etching, (d), darkened certain areas, but this appearance could not be consistently produced. Near the surface, (e), the needles are absent, but numerous twinned crystals and broad angular markings, hereafter called zig-zags, are found in the polyhedral matrix.

The change in structure from the surface inward is shown in Fig. 2. The structure of the left hand third is martensitic and contains no free cementite, grain envelopes, needles or zig-zags. That next toward the center contains free cementite, twins and angular markings, but no well-developed needles and is the structure referred to as that of the edge. The normal structure of the interior just begins on the extreme right. This condition is typical of all specimens quenched from the high temperature.

A smaller specimen, $\frac{1}{4}$ -inch in diameter, had a structure characteristic of the edge throughout, Fig. 3 (a) and (b). In this case a white zig-zag suggestive of lightning was found near the center (a) and was not removed by deep polishing (c). Twins and slip-bands were produced in this specimen by squeezing in a vice, (d) and (e).

To investigate the possibility of a relation between the acicular structure and the shape of the specimen other forms were used, namely, a sphere and a cylinder with a ratio of length to diameter of 4 to 1, Fig. 4. For comparison the structure of a standard shape is given as etched in picric acid, (e), and in sodium picrate, (f). The differences, however, do not appear to be significant.

A comparison of Fig. 4 (e), oil quenching, and Fig. 1 (c), water quenching, shows no appreciable structural difference for these extremes of quenching rate. Further experiments in decreasing the cooling rate were undertaken with the object of producing the next lower order constituent, Fig. 5. Quenching a larger specimen in oil, (a), did not accomplish this. As specimens of still larger diameter were not available it was necessary to resort to air-cooling. A $\frac{1}{4}$ -inch diameter specimen cooled before a drying fan produced the desired result, (c) and (d). The black constituent is evidently troostite equivalent to that formed in martensitic steels on quenching. It is uniformly distributed over the whole section except at the extreme edge and is surrounded by a matrix identical to that produced by faster cooling. Cooling at a still slower rate produced only troostite, (b).

Having determined the conditions necessary to produce austenite in this steel, the effect of tempering on its structure was examined. Fig. 5 (e) shows the structure of the interior as quenched in water and (f) as tempered at 200 degrees Cent. In Figs. 6 and 7 the results of higher tempering temperatures are shown for the interior of the specimen on the left and for the edge on the right. Tempered at 200 degrees Cent., a new brown lens-shaped constituent has appeared and at 250 degrees Cent. has extended over the greater portion of the section. However, there is no definite indi-

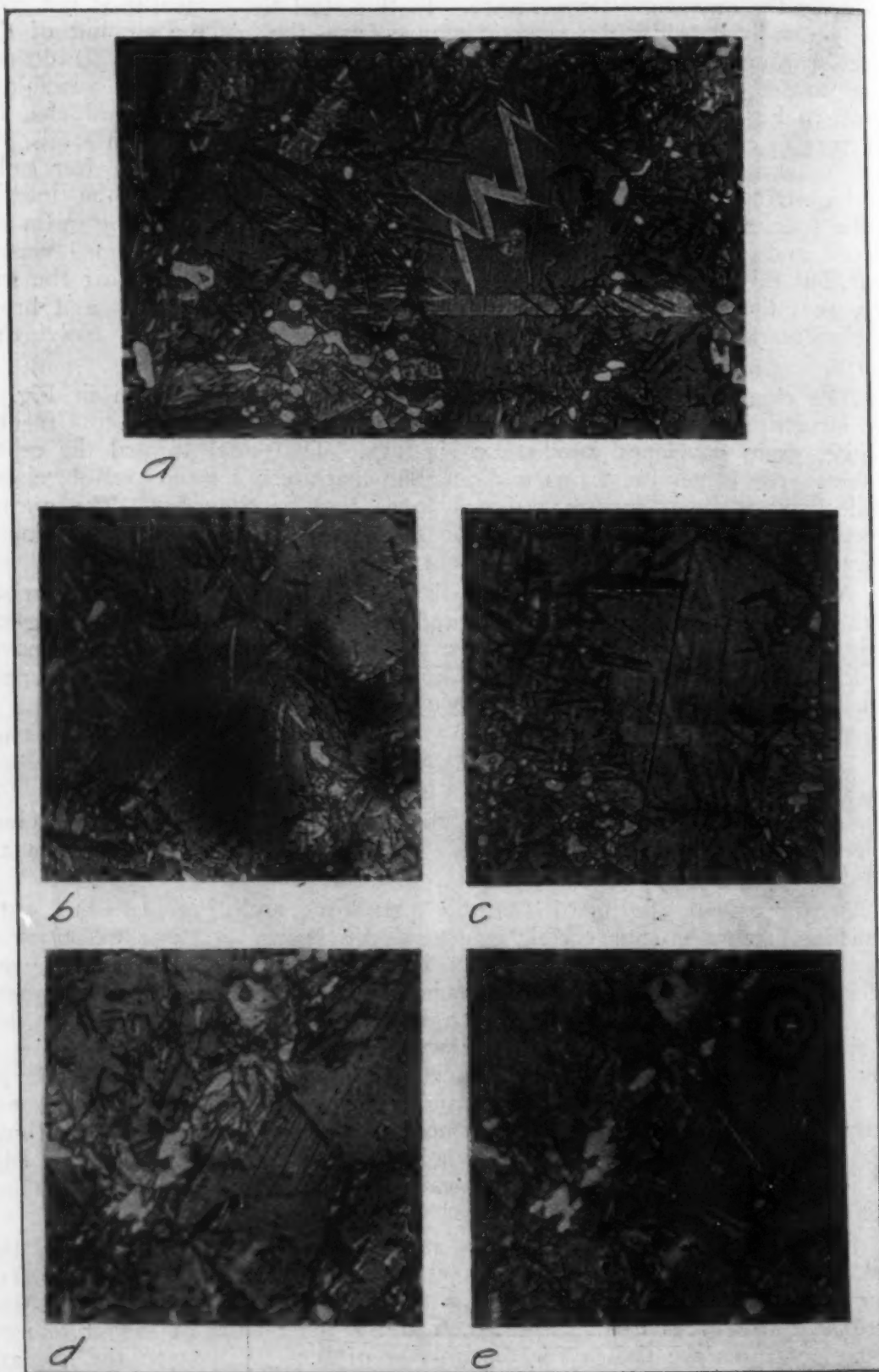


Fig. 3.—Specimen of steel A $\frac{1}{4}$ -inch diameter quenched in water from 1080 degrees Cent. (a), twin and zig-zag in a large grain near the center; (c), the same after deep polishing; (b), twins near the edge; (d) and (e), twin and slip-bands produced by strain. X 450.

cation of tempering near the edge. After tempering at 300 degrees Cent., the original white matrix has completely disappeared in the interior, though a few splotches are left in the edge area. Tempered at 350 degrees Cent. the change is complete at the edge also and the zig-zags are now lighter colored than the matrix. Tempering in the sorbite range of martensitic steels produced a typical sorbitic structure for 600 and 700 degrees Cent., but precipitated cementite particles could not be resolved, with the microscope used, for 520 degrees Cent. At 700 degrees Cent. the needles and grain envelopes are broken up into strings of fine cementite particles and the zig-zags may be distinguished, but are again darker than the body of the specimen.

Besides etching in picric acid, the specimen as tempered at 350 degrees Cent. and at 700 degrees Cent. was etched in hot sodium picrate, Fig. 8 (a) and (b). Photomicrographs (c) and (d) of this figure are of the manganese steel quenched and tempered at 530 degrees Cent. and 800 degrees Cent. The needles developed in this steel on tempering at 530 degrees Cent. break up into round particles on higher tempering as do those of the austenitic carbon steel.

In order to obtain further evidence regarding the nature of the constituent assumed to be austenite, specimens quenched from 1000 degrees Cent. and 1080 degrees Cent. were polished and dipped in liquid air, Fig. 9 (a) and (c). The latter specimen was then etched, (d). Photomicrographs (b), (e) and (f) are the results of grinding off the roughened surfaces, polishing and etching. The effect of the liquid air treatment on the specimen quenched from 1000 degrees Cent. was slight, but the specimen quenched from the high-temperature showed deep roughening of the surface and fine white zig-zags in the matrix of the interior when etched which were developed to considerable size near the edge.

Identification of Constituents

The microstructure of the austenitic carbon steel appears complex, but the important constituents are easily identified. The assumption that the matrix of this steel is austenite is substantially justified by its characteristics. First, it has the simple polyhedral structure, neglecting the needles, of solid solutions. Second, twins are produced in it by cold deformation or simply by the quenching. Third, a buckling of the surface is developed on cooling to the temperature of liquid air and the microstructure revealed on subsequent etching is suggestive of martensite. Fourth, it is tough, for it displays slip-bands on cold deformation and does not crack from the radical quenching. Fifth, there is a decided change in the microstructure on tempering. It is immediately evident that these characteristics are common to austenitic alloy steels, but are not found in martensitic steels.

Westgren and Phragmen (18) furthermore show from X-ray spectrum analysis that a carbon steel of 1.98 per cent carbon content quenched in water from 1000 degrees Cent. and 1100 degrees Cent. is predominantly austenitic. A faint trace of martensite observed by them is evidently due to decarburization, which is present, as shown later, in specimens quenched from these temperatures.

Another easily recognized constituent is the free cementite found in all specimens except at the extreme edge. It appears in three forms: massive cementite, grain envelopes, and needles. The first two forms are readily distinguished by their contour, whiteness on acid etching and darkening on

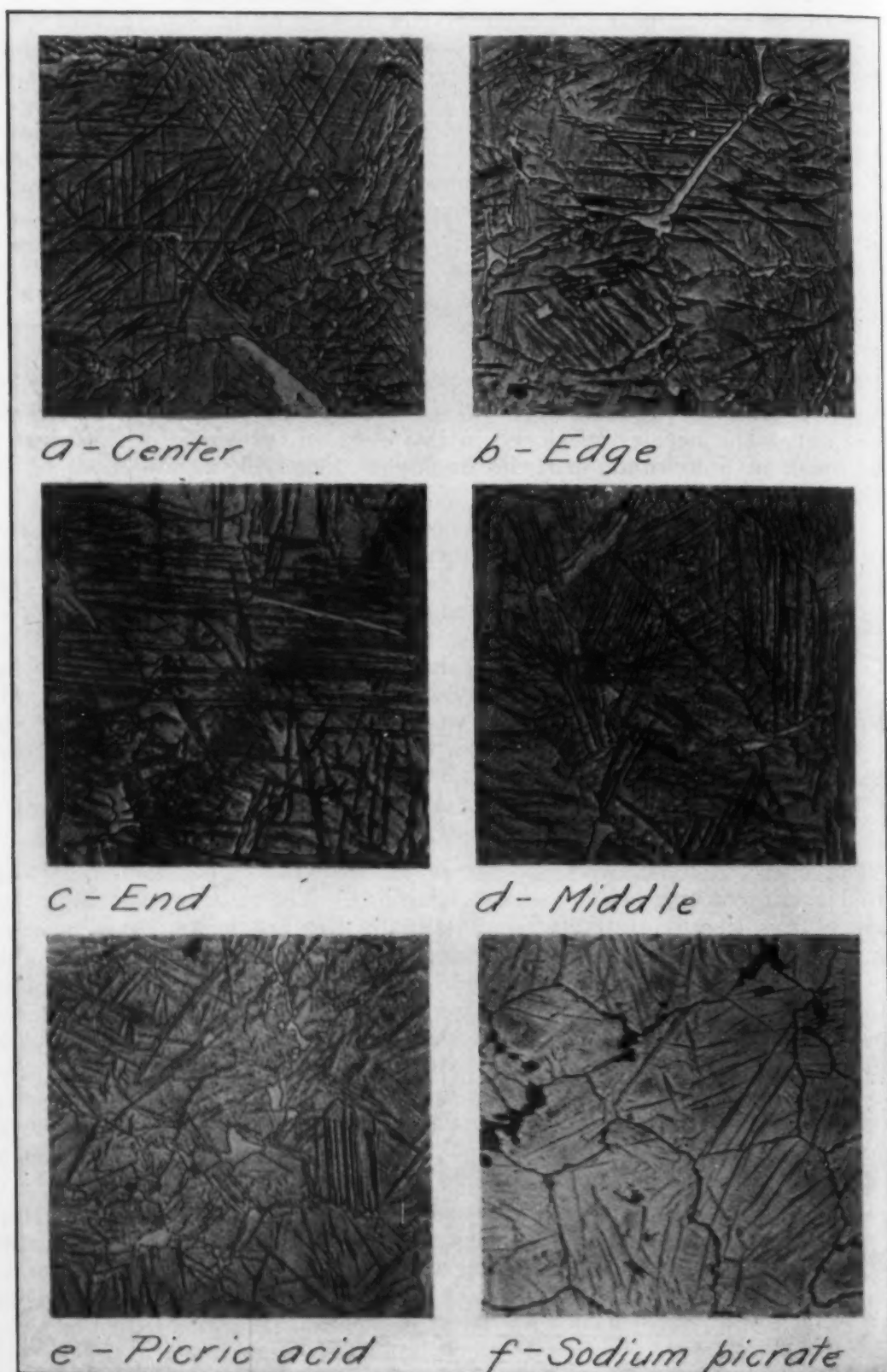


Fig. 4—Specimens of other shapes quenched in oil from 1080 degrees Cent. (a) and (b) sphere 0.55-inch diameter; (c) and (d), cylinder 0.30-inch diameter and 2 inches long; areas near surface of section at $\frac{1}{4}$ -inch from end, (c), and at the middle, (d); (e) and (f), interior of standard cylinder etched with picric acid, (e), and hot sodium picrate, (f). X 460.

sodium picrate etching, but the needles are somewhat confusing. These needles, plates in three dimensions, appear dark on acid etching as they are very thin and etch in relief, but have a white backbone when in focus. They also connect with cementite grain envelopes, darken on sodium picrate etching and spheroidize on tempering as is characteristic of cementite. These cementite needles evidently separate from the solid solution saturated at 1080 degrees Cent. for they are not present in the original structure. The austenite must then contain in solution at ordinary temperatures less than the amount of carbon dissolved at 1080 degrees Cent., that is, less than about 1.6 per cent. The absence of free cementite near the surface after high-temperature heating shows that decarburization has occurred there and this is probably responsible for the structural zones. On the other hand the closely packed cementite plates in the interior probably prevent the formation of twins there.

A third constituent referred to as zig-zags is found near the edge of specimens quenched from the high temperature. The constituent appears first, moving from the center toward the edge, when the area free from long cementite needles is reached and becomes more abundant as the edge is approached finally merging with the martensite shell, Fig. 2. Lighter, but otherwise similar, zig-zags are formed in the austenite when dipped in liquid air and in this case are unquestionably martensite. It is also highly probable that the dark zig-zags are martensite for tempered to sorbite they contain fewer cementite particles than the body of the specimen as noted by Haneman (3) and confirmed here.

The constituents of tempering an austenitic carbon steel are evidently continuous with those of a martensitic steel except that the formation of troostite proceeds in two stages. This change must be completed just above 250 degrees Cent. in the interior of the specimen according to the micrographs, for the transformation proceeds at an increasing rate with temperature. This agrees exactly with the evidence from heating curves of an austenitic carbon steel (5) which show the change is completed at 260 degree Cent. for a very slow heating rate. Martensitic steels are completely decomposed to troostite at the same temperature which indicates that the austenite transforms to martensite before decomposing to troostite and this is verified by the changes in physical properties accompanying tempering, page 554 of the above reference.

Critical Cooling Rate

A significant feature of the cooling rate experiments leading to the production of troostite in an austenite matrix is the very slow cooling rate at which austenite was obtained. Previous expressions of the conditions necessary for the retention of austenite in carbon steels state that a very fast cooling is required besides a high temperature and carbon content. However, austenite was produced inside a martensite shell and therefore at a slower cooling rate than the martensite, the essential difference being that of carbon content. It was also produced with a cooling rate much slower than that required normally to produce martensite, namely, air cooling. For the high quenching temperature there was no constituent found intermediate between austenite and troostite so the determining factor as to whether austenite or martensite will be had at ordinary temperatures is not the cooling rate, so long as it is fairly fast, but the temperature, or, generally stated, the amount of carbon retained in solution.

The critical cooling rate for the retention of austenite, that is, the slowest cooling rate at which austenite can be retained without troostite forming, is

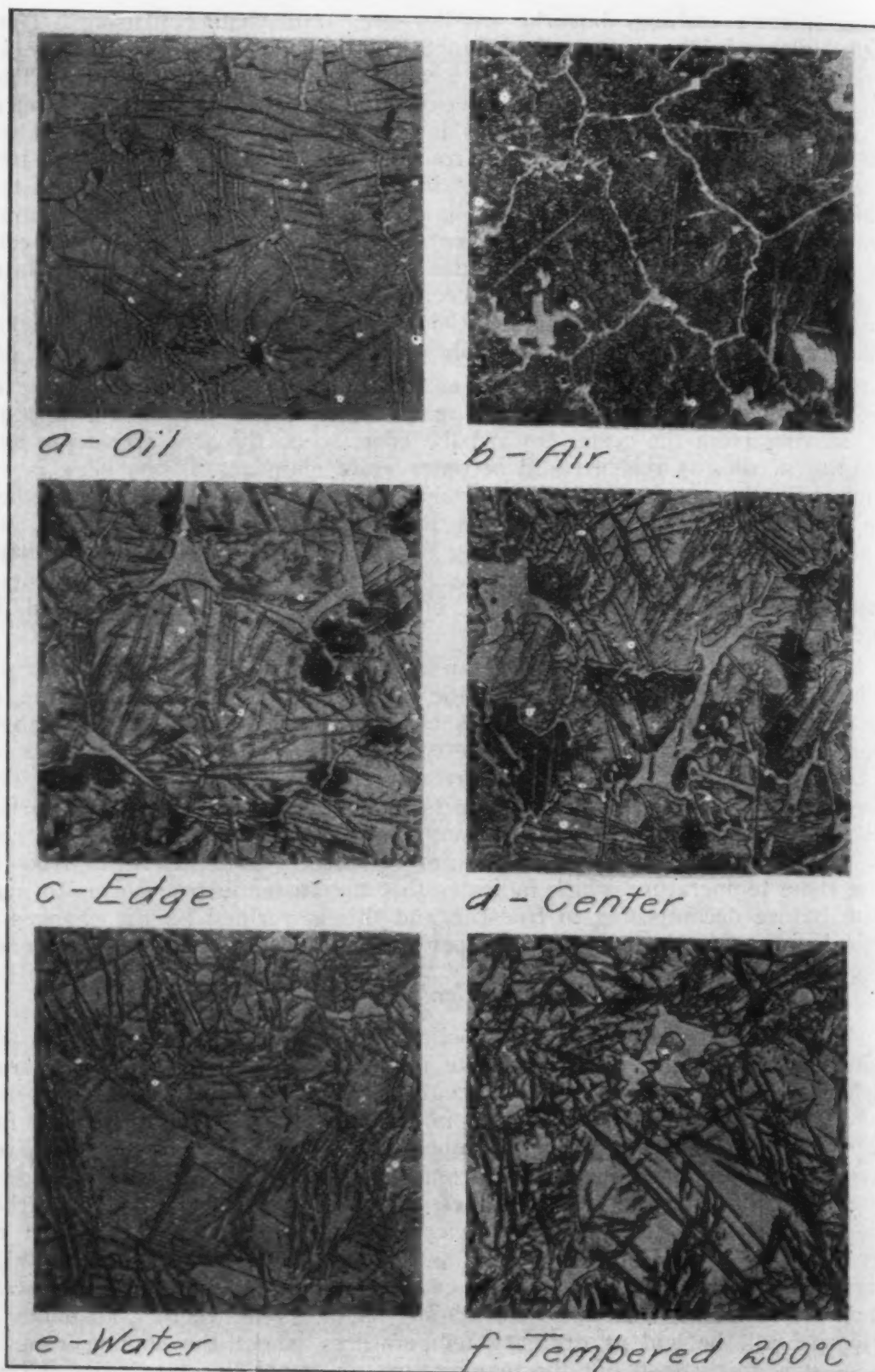


Fig. 5—Cylinders of steel A cooled from 1080 degrees Cent. at different rates; (a), $\frac{5}{16}$ -inch diameter quenched in oil; (b), $\frac{1}{2}$ -inch diameter cooled in still air; (c) and (d), $\frac{1}{4}$ -inch diameter cooled in mild air-blast; (e), $\frac{1}{2}$ -inch diameter as quenched in water and (f) same tempered at 200 degrees Cent. X 465.

obviously much slower for austenitic carbon steels than for martensitic carbon steels. This phenomenon is explained, at least in part, by the experiments on martensitic carbon steels described in the following section.

Macro and Microstructure of the Martensitic Steels

The most striking feature of the martensitic steels is the distribution of quenching troostite in the presence of martensite. To reveal it the specimens were sectioned as before and etched with 5 per cent nitric acid in methanol, which reagent produces better contrast between the constituents under examination than picric acid. The entire sections were then photographed at a magnification of 4 diameters and are reproduced in Figs. 10 and 11.

The effect on the B steel of varying the cooling rate from 1080 degrees Cent. by the use of different cooling media is shown in the first four pictures of Fig. 10. The black constituent is of course troostite of quenching and the white martensite. The fastest quenching, (a), produced a section the majority of which was martensitic, but with a quarter-moon of troostite on one edge. The next less drastic quenching, (b), resulted in two crescents of noncontinuous martensite on opposite edges and some small patches in the center. Oil quenched specimens, (c) and (d), contained a few small spots of martensite in the central portions only. The results of water quenching from 960 degrees Cent. and 800 degrees Cent. are shown in (e) and (f) respectively. Martensite occupies about half the area and one side only of the former, but less than half of the latter taking the shape of two opposing crescents concave inward. In no case does the martensite completely enclose the troostite as a continuous rim unless the specimen be vigorously stirred, Fig. 11 (a). Quenching in oil from 800 degrees Cent. produced no martensite, Fig. 11 (b).

As is commonly known, a steel near the eutectoid composition hardens deeper than higher carbon steels. Steel C illustrates this. A mild water quench from 1080 degrees Cent., Fig. 11 (c), produced martensite over the whole section except at the extreme edge where troostite is visible only at higher magnifications. The gray curved bands in this macrograph and also the dark spot in the martensite at the bottom of Fig. 10 (f) are not the black troostite of quenchings, but merely reddish-brown areas in the martensite which photograph dark. Quenching in oil also produced martensite over the whole section, Fig. 11 (d), but it takes the form of a discontinuous aggregate cemented by troostite. The troostite forms only grain envelopes in the outer portions, but is more concentrated near the center. Water quenching from 800 degrees Cent. also resulted in the formation of martensite throughout the section, but it is interspersed with troostite in the central region. Quenching in oil from the same temperature, however, failed to produce any martensite, Fig. 11 (f).

The microstructure of some of these specimens also shows noteworthy features. Fig. 12 gives the structure of the B steel as quenched from 1080 degrees Cent., (a); (b) and (c), and of the same specimen polished, dipped in liquid air and then etched, (d), (e) and (f). There was no roughening of the surface developed by the liquid air treatment, but the martensite needles etch in bolder relief. In Fig. 13 are shown the results of water quenching from 960 degrees Cent., (a), (b) and (c) and from 800 degrees Cent., (d), (e) and (f). These correspond to the macrographs of Fig. 10, (e) and (f), respectively. There is considerable free cementite after the 800 degree Cent. quench, but none following the higher temperature quenches.

A spot of the martensite in the center of the B steel as quenched in oil, macrograph of Fig. 10 (c), is shown in Fig. 14 (a) and (b). An acicular

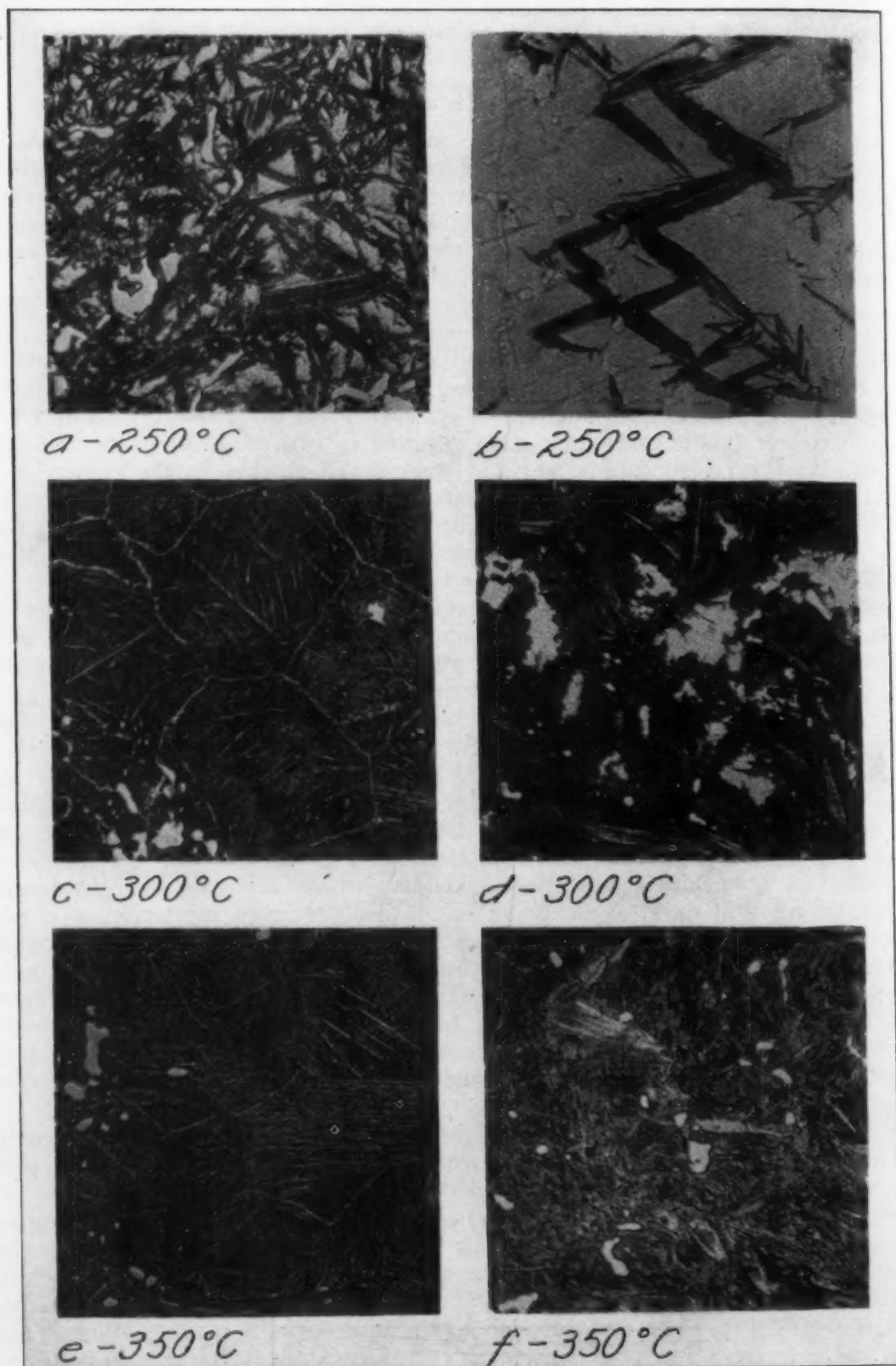


Fig. 6.—Steel A quenched in water from 1080 degrees Cent. and tempered at the temperatures noted. (a), (c) and (e) are structures typical of the center and (b), (d) and (f) of areas near the edge. X 460.

structure is developed, but it does not have the contrast of that produced by faster cooling.

The microstructure of different areas of the C steel, the macrostructure of which is given by Fig. 11 (c), is shown in Fig. 14, (c), (d) and (e). The dark lines of (c) are evidently cracks outlining the grains. Photomicrograph (d) of this figure shows the typical structure of the main body of the specimen and (e) that of the extreme edge. The troostite shown here only extends to the depth of a few grains. The same steel quenched in water from 800 degrees Cent. furnished the familiar structure of Fig. 15 (a) and (b).

Troostite Formation in the Martensitic Steels

The distribution of troostite in the martensitic steels is quite different from what might be expected according to the general impression that rate of cooling alone determines where it will be formed. This conception, however, neglects a very important variable in phase relations, namely, stress. Since a body cannot be heated or cooled without the development of temperature gradients and a temperature gradient produces stress in any body having a definite expansivity and elasticity, it is evident that stress is an ever present factor in the heat treatment of steel. Obviously, then, there are three factors which enter into this problem, namely, the transformations, the cooling rate distribution, and the stresses present in cooling steel. In regard to troostite formation, however, the status of stress is important only at the time of transformation.

The Transformations in Cooling Steel

The transformations occurring in cooling steel have been extensively studied in recent years and the effect of the most important variable, rate, has been definitely established. The significant facts are most concisely presented in the form of idealized curves, Fig. 16. Here Ar' is the familiar eutectoid transformation at which austenite transforms on slow cooling into pearlite or its equivalent in alloy steels. Ar'' is the lower temperature transition of austenite to martensite and Ar' is the continuation of Ar_1 for rates at which troostite forms from austenite. Between the cooling rate limits A and B both Ar' and Ar'' occur if the steel be cooled to a low enough temperature. The cross-hatched areas indicate the variations in intensity of the respective transformations and between A and B show the relative proportions of the final constituents, troostite and martensite, or austenite if Ar'' is below normal temperatures.

This generalized diagram applies to the areas of eutectoid composition, but is easily modified to fit any particular steel. Of special interest here is the effect of free cementite which dissolves and lowers Ar'' as the quenching temperature is raised. If sufficient carbon be held in solution, Ar'' will be depressed below ordinary temperatures and the steel will then be austenitic, for example, steel A quenched from the high-temperature.

The information on which this diagram is constructed is contained with further references in several previous papers (6, 7 and 10). The nomenclature used, with the exception of the distinction between Ar' and Ar_1 , is that of Portevin. This distinction, as expressed by the figure, is justified by the fact that Ar_1 is abrupt and Ar' continuous (10) and (11), so the maximum of the latter must be lower than the former even if both start at the same temperature.

An important ordinate on the cooling rate diagram is that of the critical

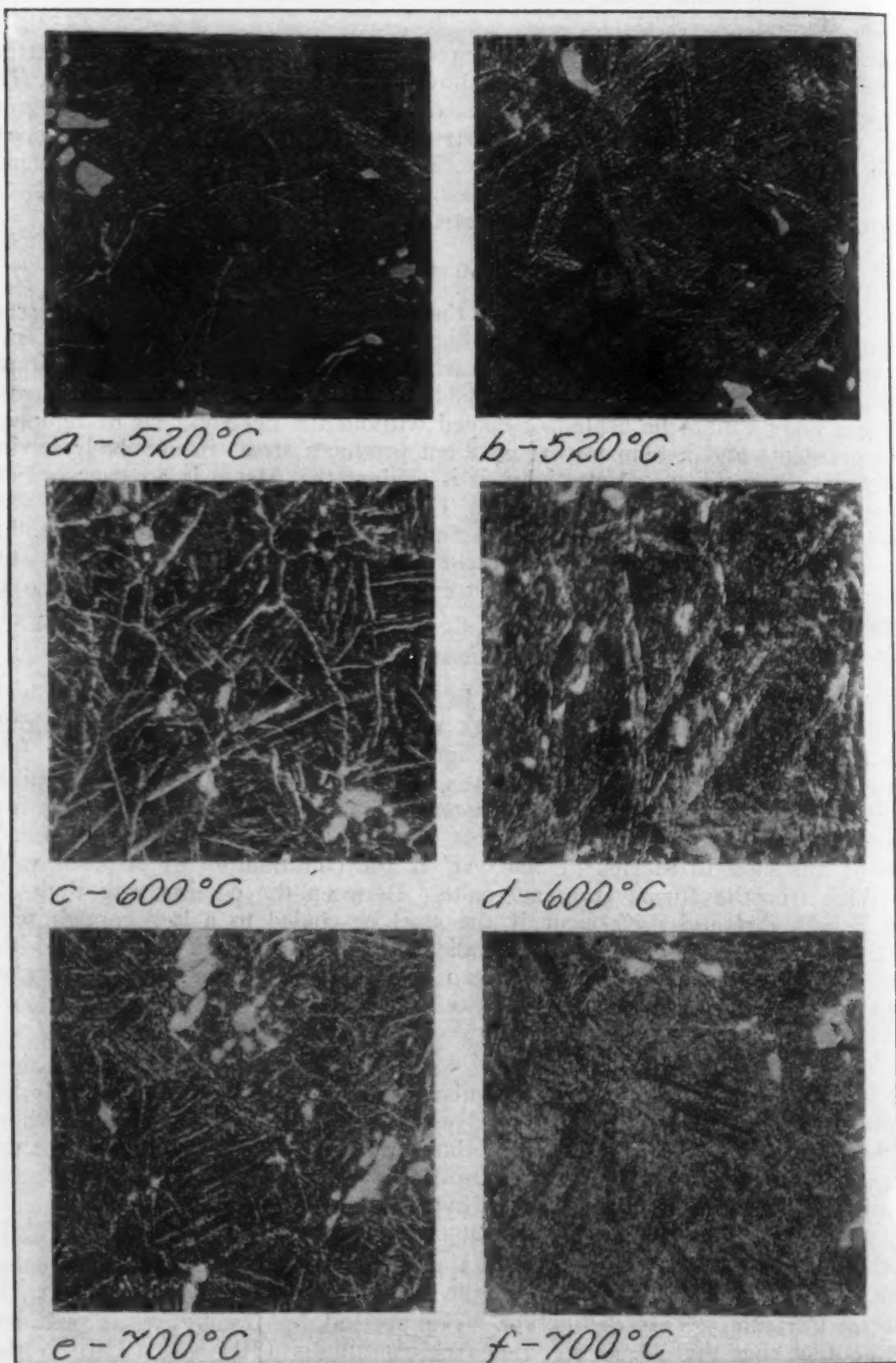


Fig. 7.—Same specimen as Fig. 6 tempered at higher temperatures. (a), (c) and (e) are structures typical of the center and (b), (d) and (f) of areas near the edge. X 465.

cooling rate, generally defined by the point B of Fig. 16, that is, the slowest cooling rate at which the steel can be obtained purely martensitic or austenitic. This definition is satisfactory for steels hardening with slow cooling rates in which case no serious thermal stress is developed. However, if quenching is resorted to considerable stress may be developed which will displace the position of the critical rate ordinate. This requirement of low stress is not met in Portevin and Garvin's quenching curve experiments so the critical values obtained by their method or similar methods will be referred to as apparent critical cooling rates.

Fig. 16 shows that Ar'' occurs only in the austenite which has not undergone transformation at Ar' so the final pattern is determined by the latter change. The effect of rate of cooling and of stress is then significant only as existing in areas undergoing this transformation which, in carbon steels, occurs in the neighborhood of 650 degrees Cent. One should then consider the rate distribution at this temperature rather than at a given time.

The Cooling Rate Distribution on Quenching

The temperature distribution in slowly cooling bodies is practically uniform so the rate is constant over any section, but it is not so simple in rapidly cooling bodies. It is in fact very difficult to determine experimentally the time-temperature curves for any position in bodies undergoing quenching, and the only accurate information from this source is that for the center of steel cylinders. The problem is, however, susceptible of mathematical analysis from which the desired information may be obtained. It is assumed that the surface of a simple shaped body is cooled immediately to some final temperature at which it is maintained. This is obviously the fastest rate at which the body can be cooled and one hardly possible to attain, nevertheless drastic water quenching approximates it fairly closely and according to McCance (14) the calculated cooling curves for the center of cylinders agree well with the observed curves for temperatures above Ar' . As has already been pointed out, this is the significant region of the curves.

The theoretical cooling rate distribution along a radius of a sphere is given by the slope of the time versus temperature ratio curves presented by Heindlhofer (15) and reproduced in Fig. 17. These generalized curves hold for any quenching temperature and size of sphere so long as the time ordinate is increased as the square of the radius. A similar family of curves could be constructed for long cylinders and in that case the cooling for the same diameter would be slower, but the curves would have the same relative slope at any temperature. The cylinders used are intermediate between these two cases, but since the information desired is relative only, either case will serve.

Fig. 17 shows clearly that the cooling rate at a given temperature is much faster at the edge than in the center and that its distribution is much more uniform near the center than near the edge. The effect of quenching temperature on the rate at the temperature of Ar' is, however, more clearly shown by plotting the temperature at the center and at a point 1 millimeter from the edge against time for the two extreme quenching temperatures used here, Fig. 18. These curves show the rate at the center to be faster for the higher quenching temperature than for the lower, but the rate gradient between center and edge is greater with the lower quenching temperature. In regard to the effect of quenching temperature on the rate at the center, McCance (14)

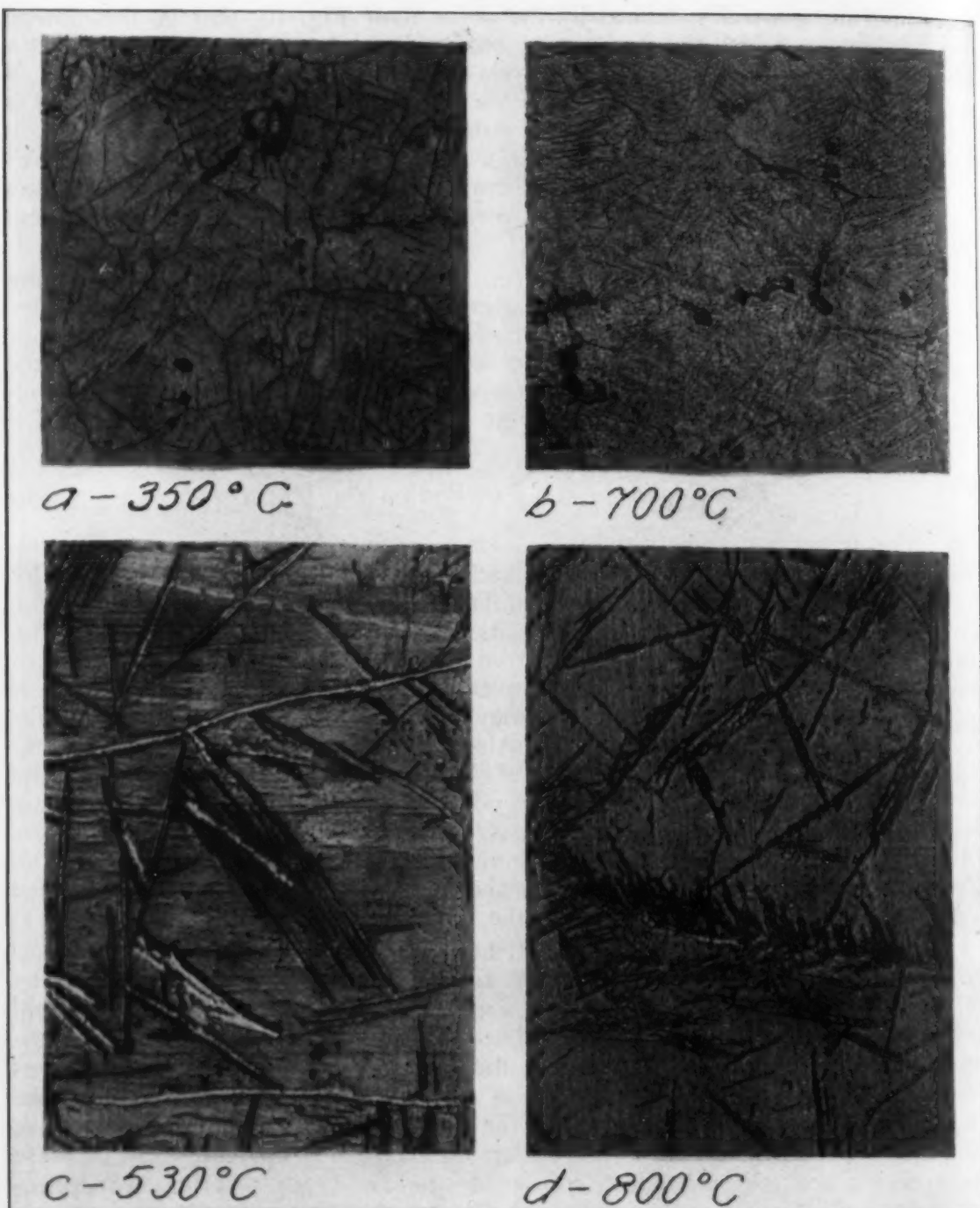


Fig. 8.—Tempered austenitic carbon and Hadfield manganese steel. (a) and (b), steel A etched in hot sodium picrate; (c) and (d), manganese steel. Both steels were quenched in water from 1080 degrees Cent. and tempered as noted. X 500.

shows that the increase at a given temperature becomes slower the higher the quenching temperature and is negligible over 1000 degrees Cent.

The Stress in Steel During Quenching

Since the distribution of troostite is determined by Ar' , the effect of stress on that change is of immediate interest. This transformation occurs with an increase in volume so, according to LeChatelier's principle, pressure

will lower the temperature at which it occurs and tensional stress raise it. Lowering this transformation represses it so pressure must restrict troostite formation and tension favor it. Portevin and Garvin (6) assume the reverse, but do not give the basis for this assumption. They argue on that assumption that a small diameter rod will have a faster critical cooling rate than a larger one and cite the dilatometric observations of Chevenard (8) as evidence. It is, however, probable that the fine wires of Chevenard were under tension to keep them taut and this would explain the high value of the critical cooling rate obtained.

The sign of the stress in rapidly cooling steel cylinders, that is, whether tension or compression, is evident from a consideration of their temperature distribution and the well-known physical properties of steel. This subject has been treated at length by Tafel (12) and the significant points only are mentioned here. Steel heated to a high temperature is practically free from stress for its elastic limit is then very low and pre-existing stresses will plastically deform the body, thus disappearing. If the body is now plunged in a liquid, the surface will quickly assume a much lower temperature than the center. At this stage the core will have a greater unit volume than the colder shell and so be under compression while the latter is in tension. The elastic limit cold is exceeded for even small temperature gradients according to Wille (13) so, since the metal is practically incompressible, the shell will be plastically stretched to conform to the core. As the interior cools to the same temperature as the shell it will also shrink, but since the shell has assumed a greater volume than normal, the stress gradient will reverse leaving the shell in compression and the core in tension. This is the condition before A_r'' is reached in the center, but it may be greatly modified by that change. However, the final stress distribution has no bearing on the present issue.

Since the thermal stresses are produced by temperature gradients, a conception of their relative magnitudes under several conditions may be had by again referring to the temperature distribution in cooling bodies. The curves of Fig. 17 show that at any time the gradient between center and edge is greater near the edge than near the center, that is, the stress is a maximum at the edge. From Fig. 18 it may be noted that the gradient is greater the higher the quenching temperature. It is also evident that a very large temperature difference exists between the center and the surface when the center reaches A_r' , about 450 degrees Cent. on quenching from 800 degrees Cent. for the conditions assumed in Fig. 18.

From this analysis the effect of extremes in the most important variables of quenching, rate of cooling, and initial temperature, on the rate and stress distribution may be stated as follows. If the cooling rate be very slow it will be uniform over any section and no appreciable stress will be developed, no matter what the initial temperature may be. If the cooling rate be that of a very drastic quench, it will be much faster at the edge than at the center, but the difference in rate between center and edge will be less for a high quenching temperature than for a low. A high quenching temperature also causes a faster rate at the center and greater stress than a low one.

The Effect of Stress on the Distribution of Troostite

In the experimental data each of the cases of extremes in cooling rate and quenching temperature shows a characteristic stress effect traceable also

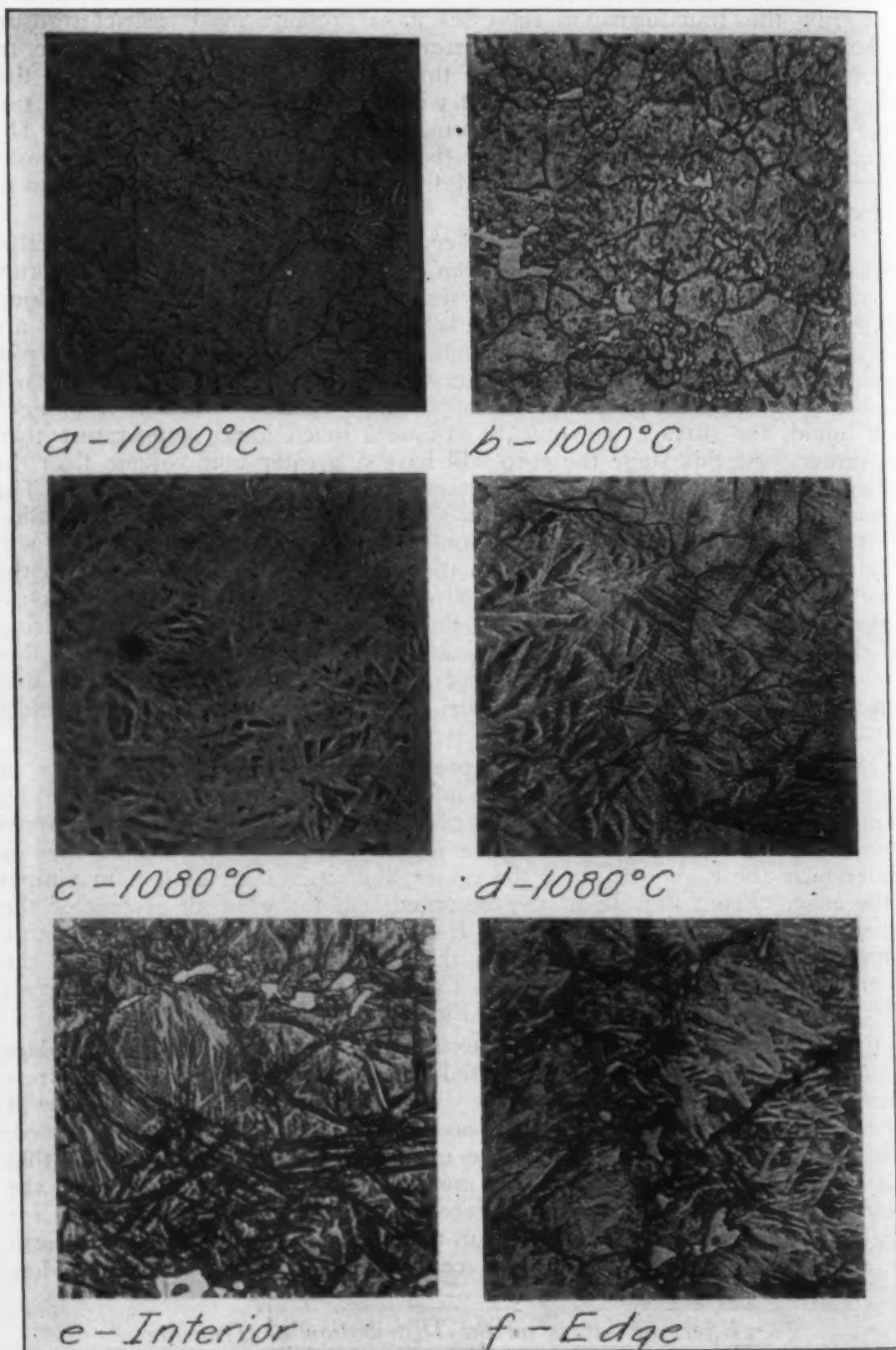


Fig. 9.—Steel A dipped in liquid air after water quenching from 1000 and 1080 degrees Cent. (a), (c) and (d), structures developed on faces polished prior to immersion in liquid air; (b), (e) and (f), repolished and etched after liquid air treatment. X 460.

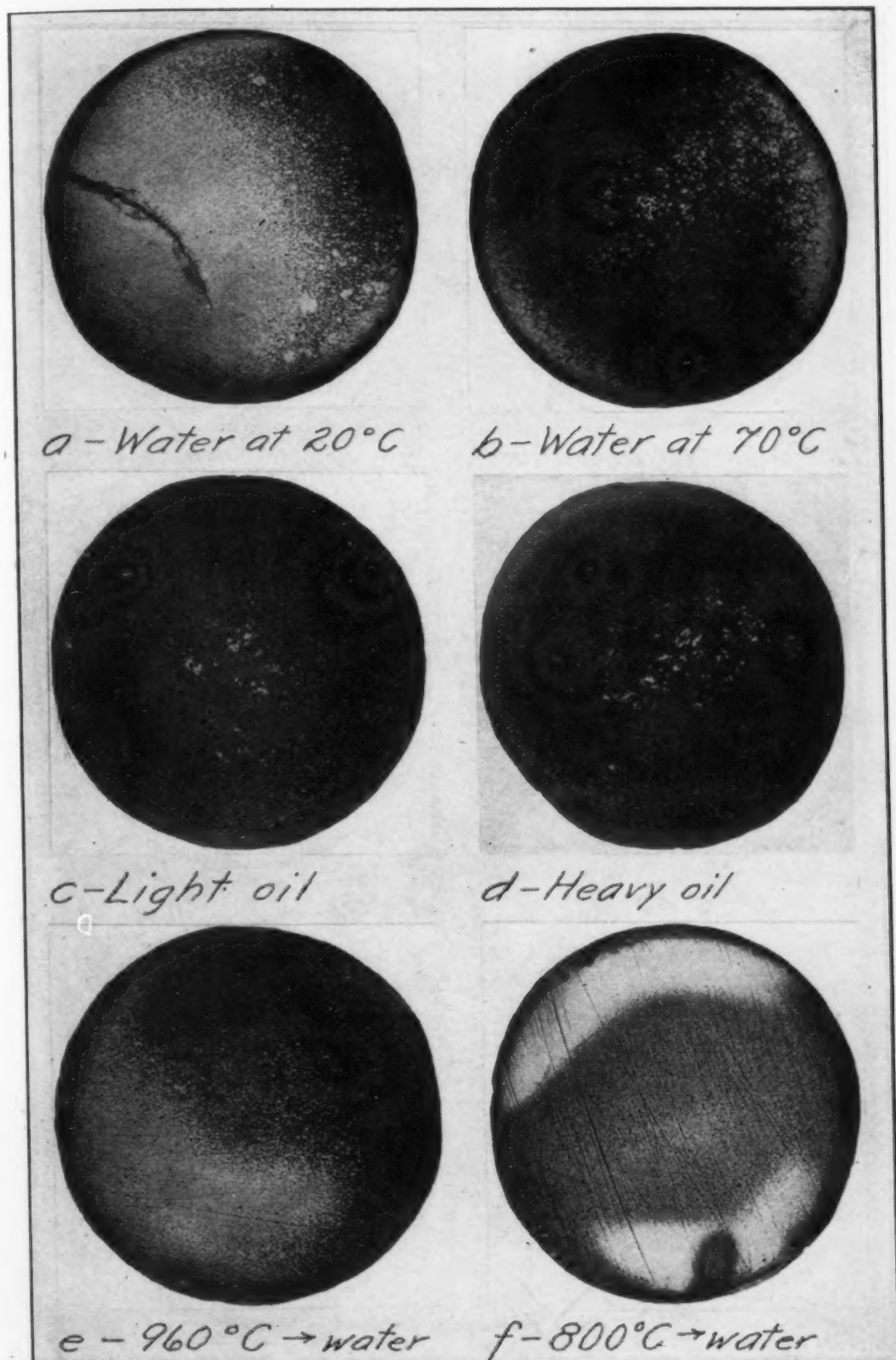


Fig. 10.—Effect of quenching temperature and medium on the distribution of troostite in a martensitic steel. Sections of steel B magnified 3¼ diameters. (a), (b), (c) and (d), quenched from 1080 degrees Cent. in medium indicated; (e) and (f), quenched in water from 960 and 800 degrees Cent. respectively.

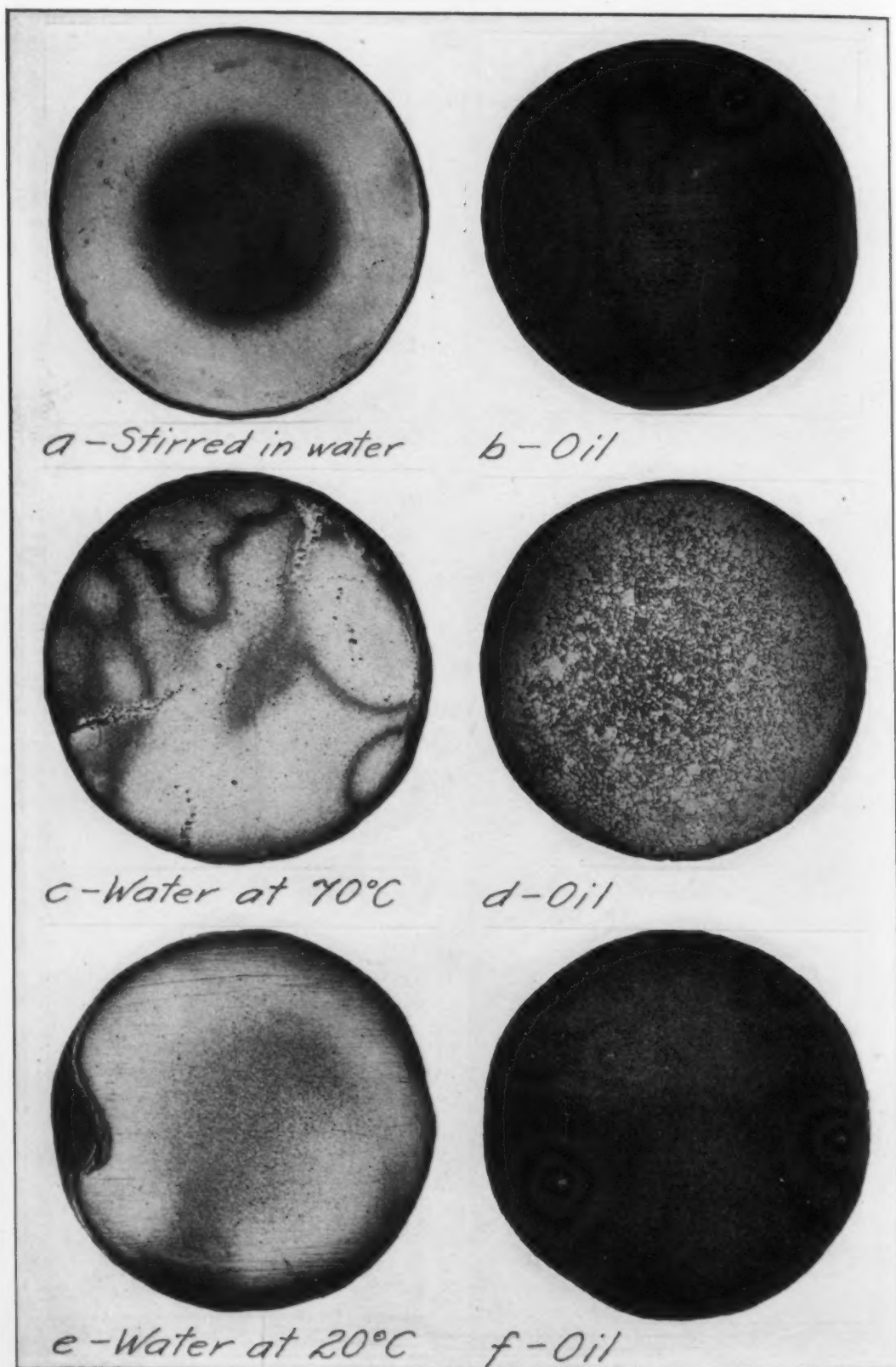


Fig. 11.—Effect of quenching on troostite distribution in martensitic steels. (a) and (b), steel B quenched from 800 degrees Cent.; (c) and (d), steel C quenched from 1080 degrees Cent.; (e) and (f), steel C quenched from 800 degrees Cent. Magnification $3\frac{3}{4}$ diameter.

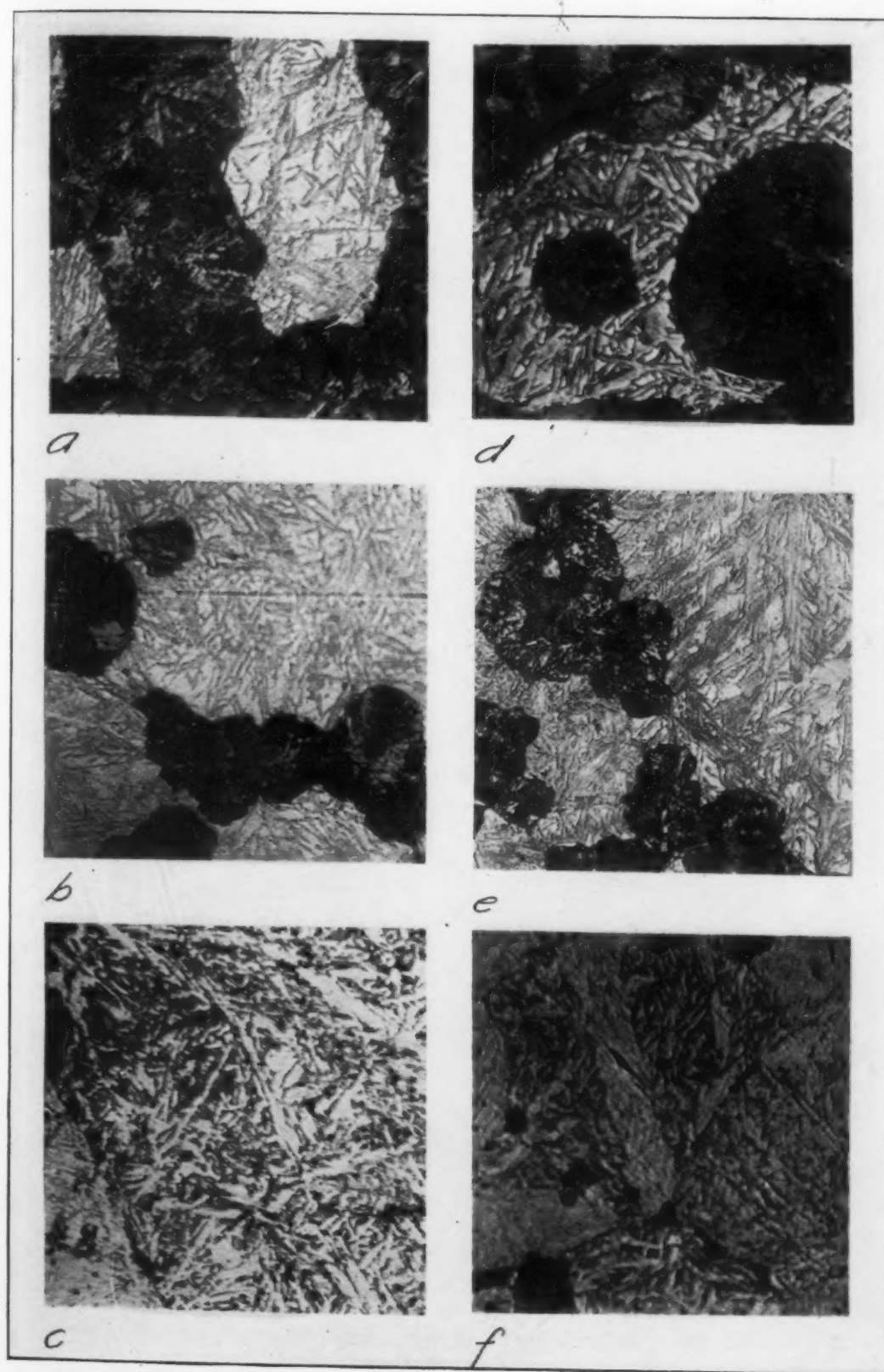


Fig 12.—Microstructure of steel B quenched in water from 1080 degrees Cent. (a), (b) and (c), as quenched; (d), (e) and (f), same polished, dipped in liquid air and etched. X 460.

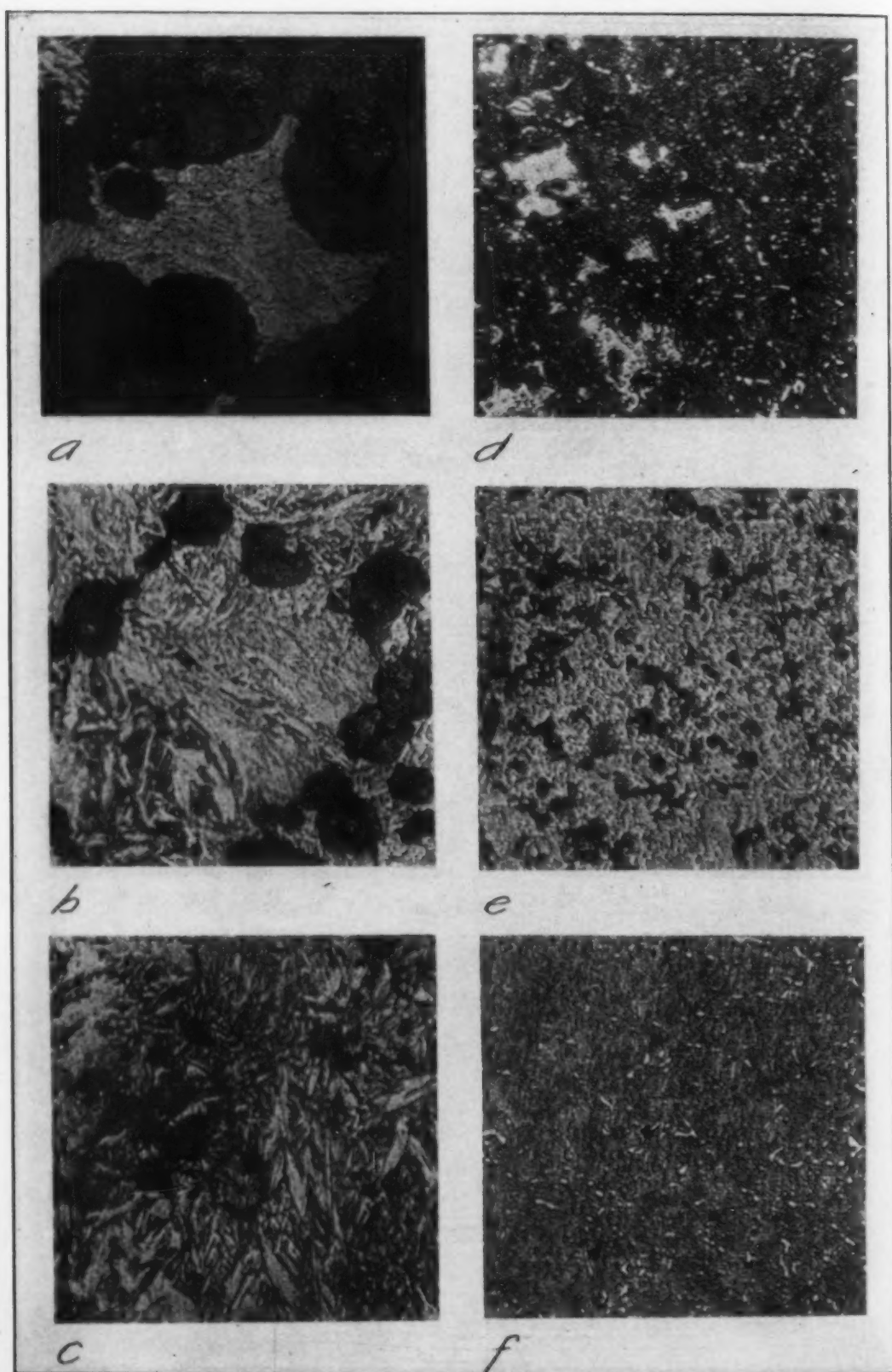


Fig. 13.—Microstructure of steel B quenched in water; (a), (b) and (c), from 960 degrees Cent.; (d), (e) and (f), from 800 degrees Cent. X 465.

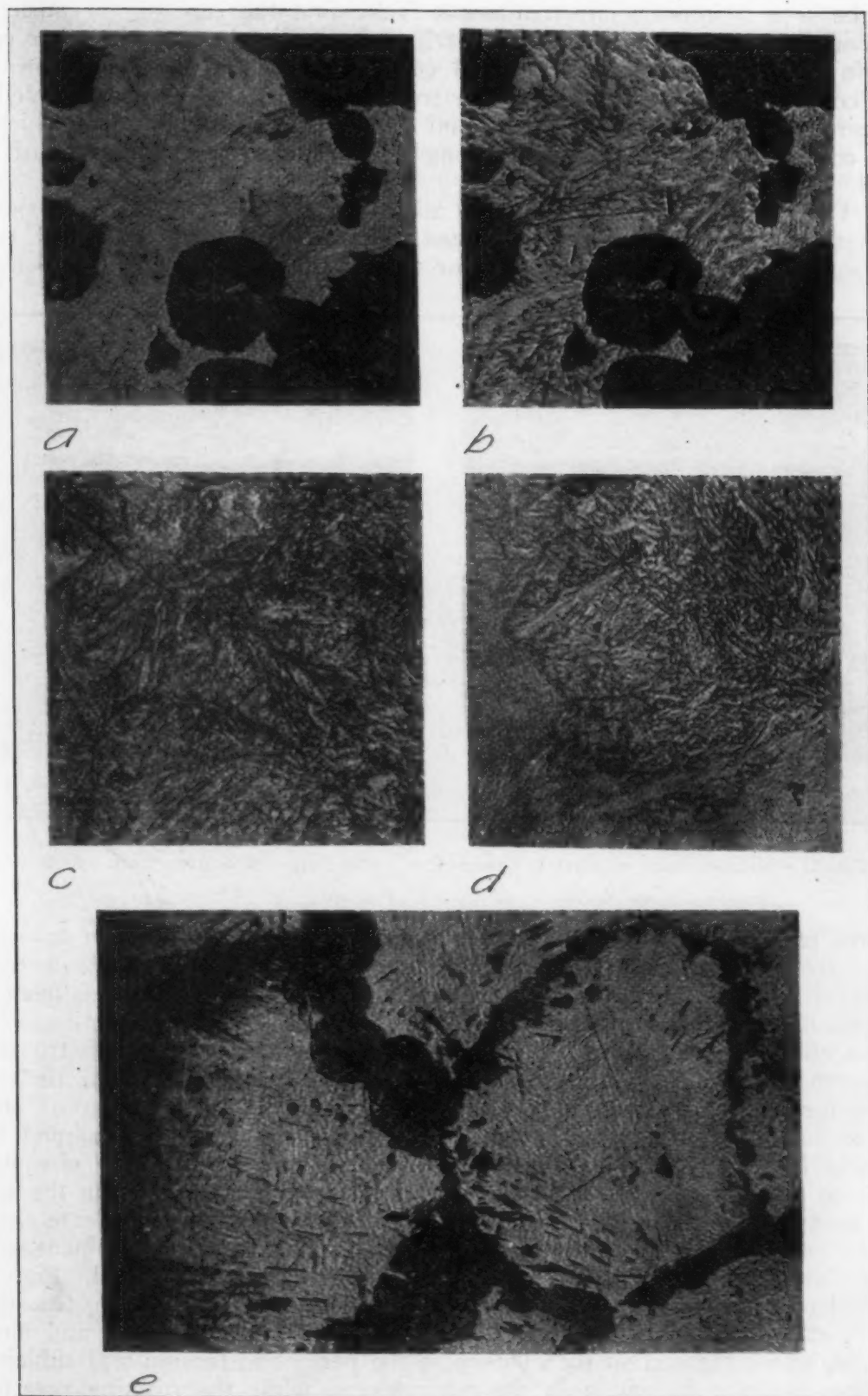


Fig. 14.—Microstructure of steels B and C. (a) and (b), martensite spot in center of specimen of steel B quenched in oil from 1080 degrees Cent.; (c), (d) and (e), steel C quenched in water at 70 degrees Cent. from 1080 degrees Cent. X 445.

in the several intermediate treatments. Take first the case of the austenitic carbon steel containing uniformly distributed troostite in austenite after cooling in a mild air-blast, Fig. 5 (c) and (d). Evidently the stress was low and the cooling rate quite uniform. The troostite was accordingly distributed as required by the cooling rate alone and so was necessarily uniform which is the condition essential for determining the true critical cooling rate of the steel.

The critical cooling rate of the austenitic carbon steel is much slower than the apparent critical cooling rates of martensitic steels quenched from the same temperature. The reason for this difference between the austenitic

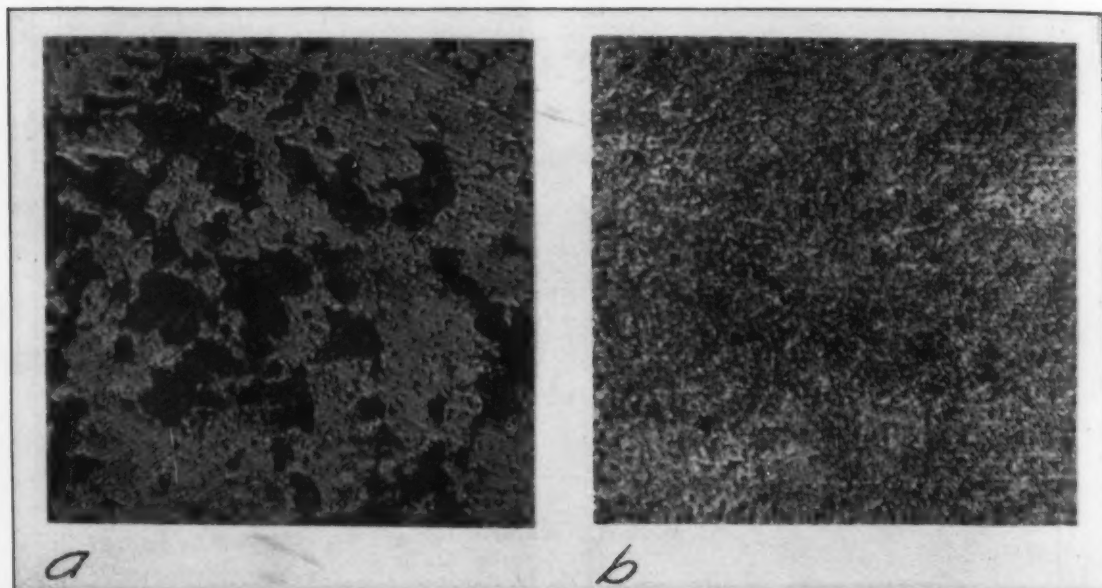


Fig. 15.—Microstructure of Steel C quenched in water from 800 degrees Cent. X 500.

and the martensitic steels is not the final state of the matrix, for the troostite forms from austenite in either case. It is probably due to a small decrease in the critical cooling rate with lowered carbon content which demands quenching and its accompanying stress effects favorable to troostite formation.

The effect of quenching stresses in abetting the formation of troostite is shown by the martensitic steels quenched from 1080 degrees Cent., the condition for maximum stress when Ar' is reached. Thus a specimen of steel C was uniformly martensitic except for a fringe of troostite adjoining the surface, Fig. 11 (c) and 14 (e). The critical cooling rate was obviously exceeded throughout the whole specimen, but the tensional stress on the surface was more than sufficient to neutralize the effect of the fast rate there and so to allow troostite precipitation. The same effect is predominant with much slower cooling rates. Specimens of steel B quenched in oil, Fig. 10 (c) and (d), had martensite in the center alone, the remainder being troostite. In this case the cooling rate was evidently near the critical value and more uniform across the section than before so the peripheral tension was sufficient to cause troostite formation in the outer layers, while the reacting pressure in the center partially suppressed that change there.

The other extreme in quenching temperature, 800 degrees Cent., reduces the stress, but does not eliminate it and causes a greater difference in

cooling rate between center and edge than the higher quenching temperatures. Thus in steel B quenched in water without agitation, the martensite was all near the surface, but was broken by troostite areas at two opposite points, Fig. 10 (f). The surface troostite is evidently due to circumferential stress and is only eliminated when the specimen is agitated in water, Fig. 11 (a), thereby cooling rapidly enough to exceed the critical cooling for that stress.

It is probable from previous considerations that the critical cooling rate of these specimens was exceeded near the center also. Quenching in water from

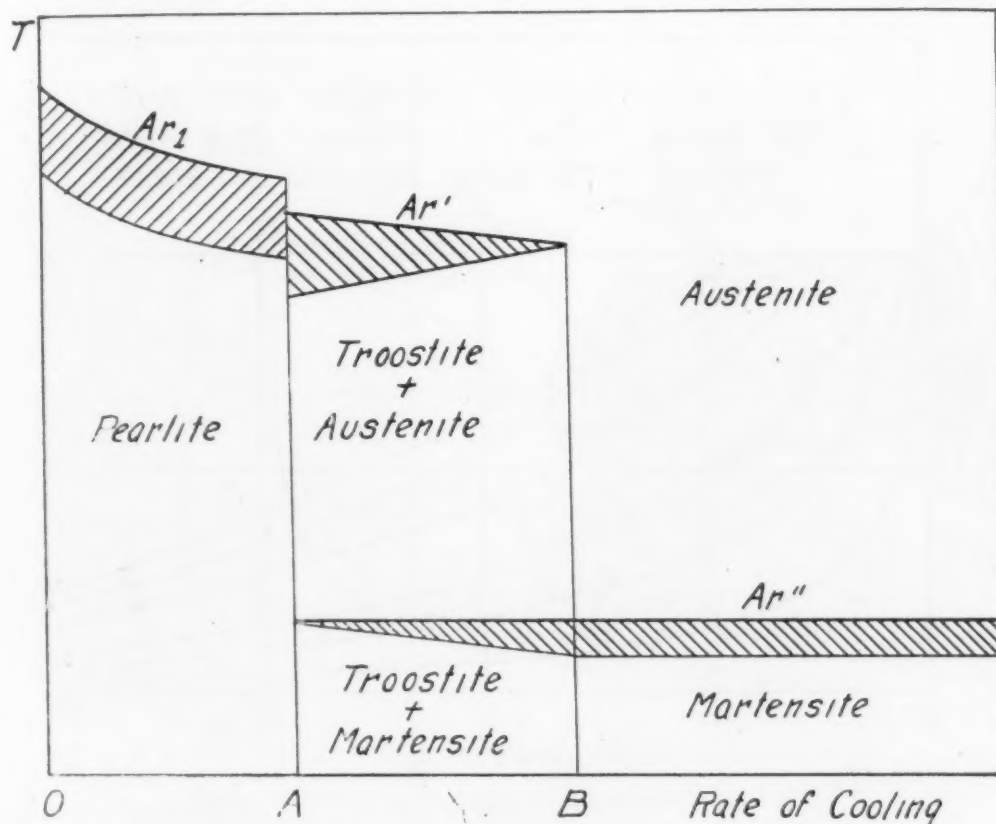


Fig. 16—Generalized diagram of transformation in cooling steel.

800 degrees Cent. certainly creates as fast a cooling rate as the center when Ar' is reached as quenching in oil from 1080 degrees Cent. Pressure must have existed there also so troostite could hardly be expected to form in the center. There is, however, another element which enters here, namely the expansion of martensite forming at Ar'' . The expansion of the hard martensite forming on the surface may easily reverse the stress in the interior from compression to tension while it is still above Ar' thereby affording opportunity for troostite to form there. A sufficiently large temperature gradient for this to occur is quite possible as Fig. 18 shows. This effect is not present on quenching from the high temperature for Ar'' is then lower and consequently is not reached in the outer layers until a much later time. Fig. 19 taken from the dilatometric quenching experiments of Honda (9) shows Ar'' , the inflection in the cooling curve, lower for a high quenching temperature than for a low one in a hypereutectoid steel and also the considerable expansion accompanying this change. Portevin and Garvin (6) observe Ar'' at the center of specimens, quenched in a manner to produce a peripheral layer of martensite, several seconds later than Ar' . This, however, does not prove

that the two transformations do not start at the same time, as required by the above view, for an appreciable time is required for the heat wave generated by Ar'' to travel through the specimen to the center where the thermocouple is situated.

The macrographs for other treatments show various combinations of the effects observed independently in the above extreme cases. Thus all the specimens of steel B quenched from 1080 degrees Cent., Fig. 10 (a), (b), (c), and (d), show martensite in the center and troostite at the edge, the to-

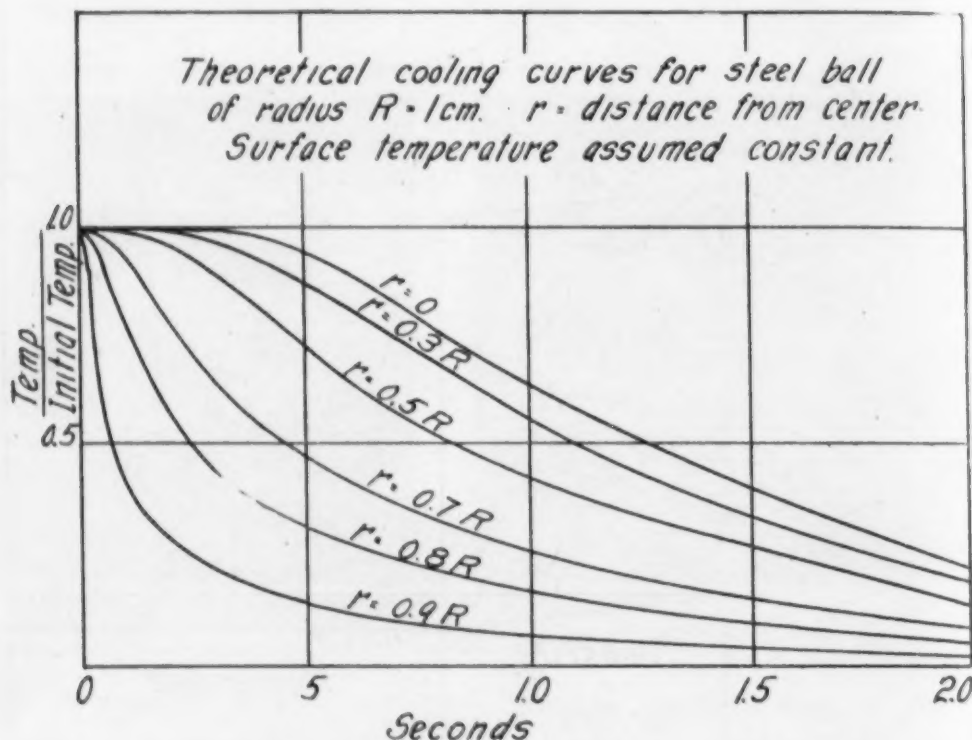


Fig. 17.—Theoretical quenching curves of a steel sphere.

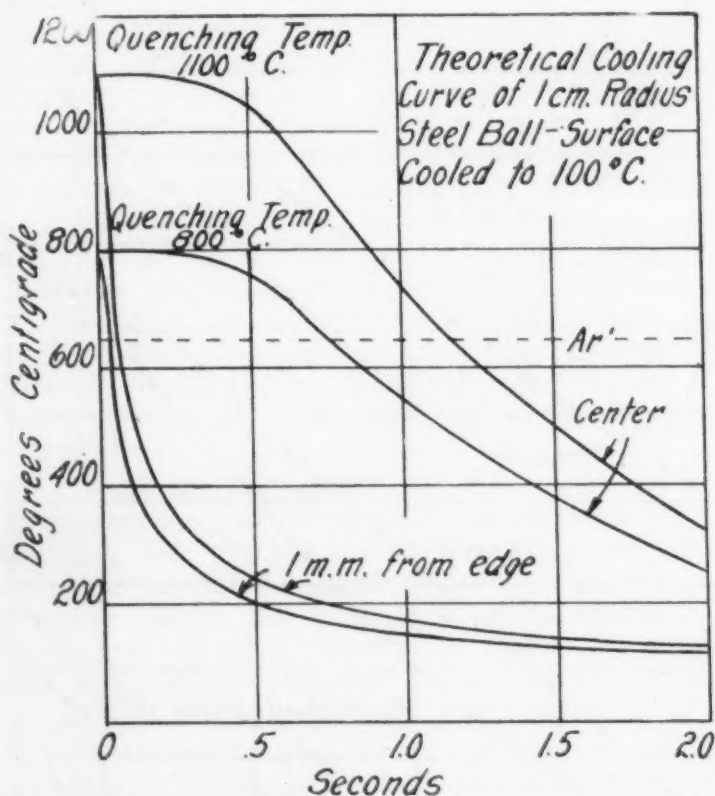
tal amount of martensite of course decreasing with lowered cooling rate. This distribution is predominant with oil quenching for the rate is then more uniform across the section. The appearance of the crack in the martensitic area of Fig. 10 (a) indicates that it occurred at a high temperature. In this case the tension in its neighborhood may have been relieved when Ar' was reached, preventing troostite formation there.

With decreasing quenching temperature, Fig. 10 (a), (e), and (f), the ratio of martensite to troostite does not change as much as might be expected from the corresponding change in the rate at the center, but the change in position of the troostite areas is very marked. This shows the effect of the sharper rate gradient and lesser stress caused by the lowered quenching temperature.

The C steel quenched in oil from 1080 degrees Cent., Fig. 11 (d), has a structure predominantly martensitic but with troostite throughout the section, somewhat more concentrated near the center. Quenched in water from 800 degrees Cent., Fig. 11 (e), troostite appears only in the center and then mixed with martensite. Accordingly this steel has a slower critical cooling rate than B steel. This difference between the two steels, however, cannot be

attributed to cementite crystallization nuclei, as suggested by Portevin and Garvin 6, for free cementite is present in both steels when quenched from the lower temperature and absent from both when quenched from the higher temperature, Figs. 12, 14 and 15. The somewhat different distributions of troostite in these two steels with the same ratio of troostite to martensite is evidently due to the considerable difference in cooling rate necessary to produce equal ratios.

The above analysis of the experimental results is based on a consideration



of stress in cooling steel. Briefly, tensional stress favors and compression hinders the formation of troostite at Ar' . The distribution of troostite is, however, dependent also on the rate distribution and subsequent transformation. By choosing conditions which bring one or another of these factors to a maximum they may be plainly revealed. An extensive study of these factors is obviously essential to a solution of the problems of hardening.

The Structure of Martensite

The information presented perhaps justifies some remarks on the constitution of martensite. This, however, requires some definite conception of the allotropic nature of martensite. The recent X-ray crystallographic studies of Jeffries and Archer (16) and of Westgren and Phragmen (18) furnish the long sought answer to this problem. These authors show that martensite has the same space lattice as ferrite and this confirms the so-called alpha-iron theory of hardening for there can be no doubt that the carbon is in solid solution. The first named authors, however, interpret the diffuse lines of

their spectrograms as showing that the grain size of martensite is very small even in steels having a very coarse microstructure. They offer this information as evidence that the hardness of martensite is due to a supposed sub-microscopic grain structure. The latter authors confirm the observation that the spectrogram of martensite is such as might be produced by very fine grains, in fact colloidal sized, and submit the additional information that the lattices of both austenite and martensite are enlarged by dissolved carbon.

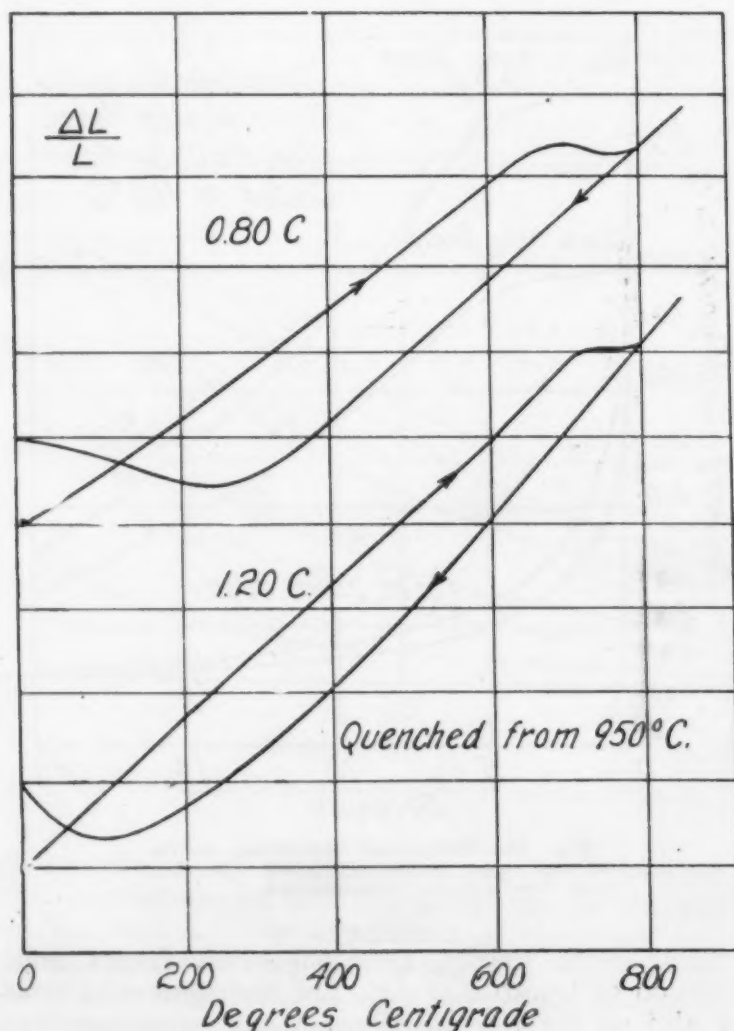


Fig. 19.—Expansion curves of an eutectoid steel and of a hyper-eutectoid steel.

Moreover, the lattice of austenite is not distorted by that element. These observations are, however, a natural consequence of the transformation of austenite to martensite.

The analogy between liquid and solid solutions has been successfully exploited so far as the eutectoid changes go and might well be extended, as by Hanemann (2), to this transformation of solid solution, austenite to martensite which is evidently analogous to that of solidification of solid solutions, for which case a dendritic or heterogeneous structure is normal. The essential difference between the phase change at A_r'' and the freezing of solid solution alloys is that in the former case the homogeneous unit in which

crystallization proceeds is the pre-existing austenite grain and in the latter case the whole melt. The development of segregation units is thereby restricted to a micro scale. Diffusion readily occurs in the austenitic steels while hot and their homogeneity is maintained cold as they undergo no transformation, their spectrum line is consequently sharp, but below the low temperature of A_r'' free diffusion cannot occur so the heterogeneity generated there is not effaced. It is accordingly a normal product of the genesis of martensite.

The units of maximum and minimum concentration in the near-eutectoid steels do not correspond to gamma and alpha-iron solutions as sometimes supposed for there is no roughening of the surface on cooling them to liquid air temperatures and the X-ray spectrum does not show the gamma lattice. Moreover, magnetic analysis at high inductions shows that martensitic eutectoid carbon steel has two definite saturation values (17) which evidently correspond to the units of maximum and minimum concentration. Martensite thus behaves as though composed of two separate constituents differing only in the amount of dissolved carbon. These units, however, are probably not sharply separated, but are continuous from one to another just as are the dendrites and filler of solid solution alloys. Now if carbon opens up the ferrite lattice as Westgren and Phragmen's results indicate, its nonuniform distribution should produce diffuseness of the X-ray spectrum lines no matter what the actual grain size may be. Thus the fact that the X-ray spectrum lines of martensite are diffuse is not conclusive evidence that martensite is exceedingly fine grained.

On the other hand the micrographs of martensite, particularly that of high temperature quenching, show none of the characteristics of severely cold-worked and very fine grained metals. Even the individual needles are fairly large and have noticeable directional properties within a grain. As Sauveur (19) points out in his comprehensive discussion of Jeffries' and Archer's paper, the evidence of submicroscopic grains is very meager and the assumption is hardly necessary to account for the hardness of martensite.

The above developed conception of the constitution of martensite accounts for other familiar characteristics of martensitic steels. The concentration units are naturally larger and better developed the higher the quenching temperature, as observed, for the grain units in which they grow are then larger; likewise they are smaller in areas enclosed by troostite than in purely martensitic areas for the same reason. The grain boundaries are not developed by ordinary etching methods for the concentration differences produce rapid etching over the entire surface completely obliterating the slight contrast between grains and their boundaries. A fair idea of the grain size for a given quenching temperature may, however, be had from such characteristics as the fracture, the contour of quenching cracks, and distribution of excess constituents.

The difference in specific volume between the units of maximum and minimum concentration is probably responsible for the brittleness and characteristic fracture of martensite. The individual grains are accordingly brittle so the fracture is of a different type from that of large-grained, but soft metals.

It is evident from these considerations that quenching temperature is not a simple variable as often supposed. For example, raising the quenching temperature of a hypereutectoid steel increases the rate of cooling and the stress developed; changes the rate distribution and probably the critical cooling rate; increases the amount of dissolved carbon and decreases the amount of free

cementite, lowers the transformation of austenite to martensite and delays its occurrence; increases the grain size and consequently the magnitude of the concentration units. Each of these variables can have an important effect on the final properties of the hardened steel. It is therefore essential in prosecuting investigations of quenching operations to choose experimental conditions which will bring these variables individually to a maximum so that those having important effects in the problem considered may be recognized and their control effected.

Summary

The results of a micrographic and macrographic study of the effect of high temperature quenching on the structure of three simple high-carbon steels are presented. These data show that a carbon steel can be made austenitic only when sufficient carbon is dissolved, about 1.5 per cent, and maintained in solution, by sufficiently rapid cooling. The critical cooling rate for so producing austenite is, however, very slow in comparison with that of martensitic steels cooled from the same temperature. The surface layers of the austenitic steel were decarburized in all cases at the high temperature obtained to a depth of not more than one millimeter producing two distinct surface layers. The outermost layers contained no free cementite and were martensitic. The intermediate area contained some free cementite, but there were abundant twins and other markings in its austenitic matrix. This condition of the surface has not been recognized in previous investigations of austenitic carbon steel.

The interior austenite produced as noted has the following characteristics:

- (1) It contains many thin needles of cementite (plates in three dimensions) forming parallel groups and a cementite network.
- (2) The cementite needles separate from the solid solution saturated at 1080 degrees Cent., leaving less than 1.6 per cent carbon dissolved in the austenite.
- (3) Twins and slip-bands are developed in the austenite, when the needles are sparse, by cold deformation.
- (4) It may be transformed into martensite by immersion in liquid air.
- (5) It shows a well-defined structural change on tempering to troostite and the temperature of the end point of this transformation agrees closely with that determined by heating curves.
- (6) The change from austenite to troostite is duplex involving the formation of martensite.
- (7) The troostite is converted into sorbite on tempering over 500 degrees Cent., and the cementite needles then disintegrate into globules.

Two lower carbon steels 1.04 and 1.16 per cent carbon were martensitic and contained no austenite when quenched from the same temperature as the austenitic carbon steel. Varying the quenching temperature and cooling medium for these steels lead to the following observations:

- (a) Their apparent critical cooling rate is faster than that of the austenitic carbon steel, but that of the lower carbon one is slower than that of the higher.
- (b) Quenching in oil from the high temperature produced martensite only in the center of the 1.16 per cent carbon steel.
- (c) Quenching the 1.04 per cent carbon steel in water from the same temperature produced martensite over the whole section except at the surface where troostite outlined the grains and formed short needles.

(d) A uniform concentric ring of martensite surrounding pure troostite was produced on quenching the 1.16 per cent carbon steel from a normal hardening temperature, only by agitating in water.

An interpretation of these phenomena is made from a consideration of the transformations, the cooling rate distribution, and the stress in steel during cooling. It is shown that troostite of quenching forms at about 650 degrees Cent. in carbon steels with an increase of volume. The interior of the specimen is under compression and the surface in tension when this transformation, A_r' , is reached in quenching. From LeChatelier's principle this favors the formation of martensite in the center and troostite in the outler layers. Thus when the cooling rate producing a mixture of martensite and troostite is slow, the rate will be uniform and the stress negligible so the distribution of troostite is uniform. If a high stress be developed with a uniform rate distribution troostite will form at the edge and martensite at the center. If the stress be low and the rate gradient from center to edge high, martensite will form at the edge and troostite at the center according to the rate distribution. Each of these distributions has been experimentally obtained.

The duplex structure of martensite is shown to be analogous to that of solid solution alloys. This conception requires that the structural units differ only in the amount of dissolved carbon. It is supported by the results of magnetic and X-ray spectroscopic analysis and explains some of the notable characteristics of martensite.

The experiments described here were performed in Prof. Sauveur's laboratory at Harvard University during the term 1920-21, and this paper is the outcome of Prof. Sauveur's suggestions and helpful interest in the work.

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EXPERIMENTS ON THE RAPID GRAPHITIZATION OF WHITE CAST IRON AND A THEORY FOR THE MECHANISM OF GRAPHITIZATION

By Anson Hayes, W. J. Diederichs and W. M. Dunlap

Abstract

The authors of this paper have described the results of experiments conducted in graphitizing white cast iron. Various heating and cooling treatments were applied to specimens of white iron for varying periods of time ranging from 1 to 60 hours. Photomicrographs were made of these, several of which are included in this paper. These photomicrographs show typical structures obtained in the investigation. The physical properties of the specimens which were tested are likewise included in this report.

The authors have formulated a theory for the mechanism of the graphitizing action which includes a discussion of the work that has been done in the past by other investigators.

IN 1916 one of the writers was engaged in instructing students in the properties of the various cast irons in the materials testing laboratory at Cornell university. The supply of malleable iron test pieces was exhausted but there was still a stock of white iron test samples on hand. It was decided to attempt to malleablize some of the latter rapidly, making use of high temperatures, and to demonstrate the properties resulting, at the same time, of course explaining the treatment to which the material had been subjected. There were two specimens which showed a surprisingly high tensile strength, the value being in the neighborhood of 60,000 pounds per square inch, but the elongation was practically nil.

Noting this high strength, numerous experiments were run which resulted in a product which consistently showed strengths ranging from 70,000 to 85,000 pounds per square inch, with elongations of about 1 per cent. Most of these products could be machined rather readily by the use of ordinary lathe tools and a finished machined piece had a surface which was rather difficult to distinguish from a similarly finished piece of steel.

Discussion of these results by the writers led to the conclusion that the imparting of appreciable elongation to this high strength material was possible from theoretical considerations. Furthermore, the possible commercial importance of such a product led the writers to institute a research in an attempt to develop it.

We have found it possible, at least in the laboratory, to repeatedly impart a considerable elongation to the resulting product by two methods while retaining the high strengths. In addition we have found it possible to produce by two methods a malleable iron which duplicates closely malleable iron annealed by the commercial process from the same heat. The total time required to produce malleable iron by these laboratory methods was about 45 hours and there is no doubt that the time required to accomplish

A paper presented by Dr. Anson Hayes before the Detroit Convention of the Society, October 2-7, 1922. Of the authors, Dr. Anson Hayes is associate professor of physical chemistry and metallography. W. J. Diederichs is associate professor of mechanical engineering and W. M. Dunlap is a graduate student of metallography, all of Iowa State College, Ames, Iowa.

the same end can be materially reduced. It seems very possible that these laboratory processes can be made of commercial importance.

It is the object of this paper to describe these experiments, to discuss the products resulting from these processes and to discuss the theory underlying the mechanism of graphitization.

Material and Apparatus

The material used consisted of two different melts and was cast in the form of one-half inch standard tensile test bars. The bars were used as cast. The analysis of the white iron from the two heats follows:

Constituent	Melt No. 1 per cent.	Melt No. 2 per cent.
Silicon	0.90	0.08
Sulphur	0.041	0.037
Phosphorus	0.181	0.178
Manganese	0.22	0.24
Total Carbon	2.24	2.39

Fig. 1 shows a photomicrograph typical of this white cast iron. This is a typically normal structure and needs no further comment. Fig. 2 shows a photomicrograph of a malleable test bar made from melt number 1 and annealed along with commercial run of work by the regular commercial method.

The average tensile test results of both the white iron and malleable iron supplied us follows:

	Melt No. 1		Melt No. 2	
	Tensile strength lbs. per sq. inch	Elongation per cent in 2 inches	Tensile strength lbs. per sq. inch	Elongation per cent in 2 inches
White iron	51,000	0	55,000	0
Malleable iron	54,000	22	57,300	19

It might be remarked in passing that these results show a material of exceptionally high quality. The heat treatment was carried out in two electric furnaces. One was a muffle furnace having a 7 x 12 inch hearth, the other was a "Hump" furnace with 10-inch diameter heating chamber. The former was controlled by a sectionally wound transformer and the latter by a rheostat in series with the furnace windings, supplemented by a set of parallel resistances making extremely accurate control possible.

The temperature measurements were made with a chromel-alumel couple, or a platinum-platinum rhodium couple both calibrated against a Bureau of Standards rare metal couple. Temperature measurements were made on a potentiometer indicator which was used for all runs except in the case where a very slow cooling was desired. In this case temperature measurements were recorded on a recording instrument. These combinations of couples and indicators were also calibrated against a Bureau of Standards reference electromotive force. All tensile tests were conducted in a 50,000 pound hand operated universal machine which was calibrated before using.

Experiments, Results and Discussion

The first series of experiments which will be indicated as experiment A, was conducted to determine the rate of graphitization at a temperature of 1000 degrees Cent. The ideal method would have been to introduce the test specimens into the furnace while at temperature so that length of time

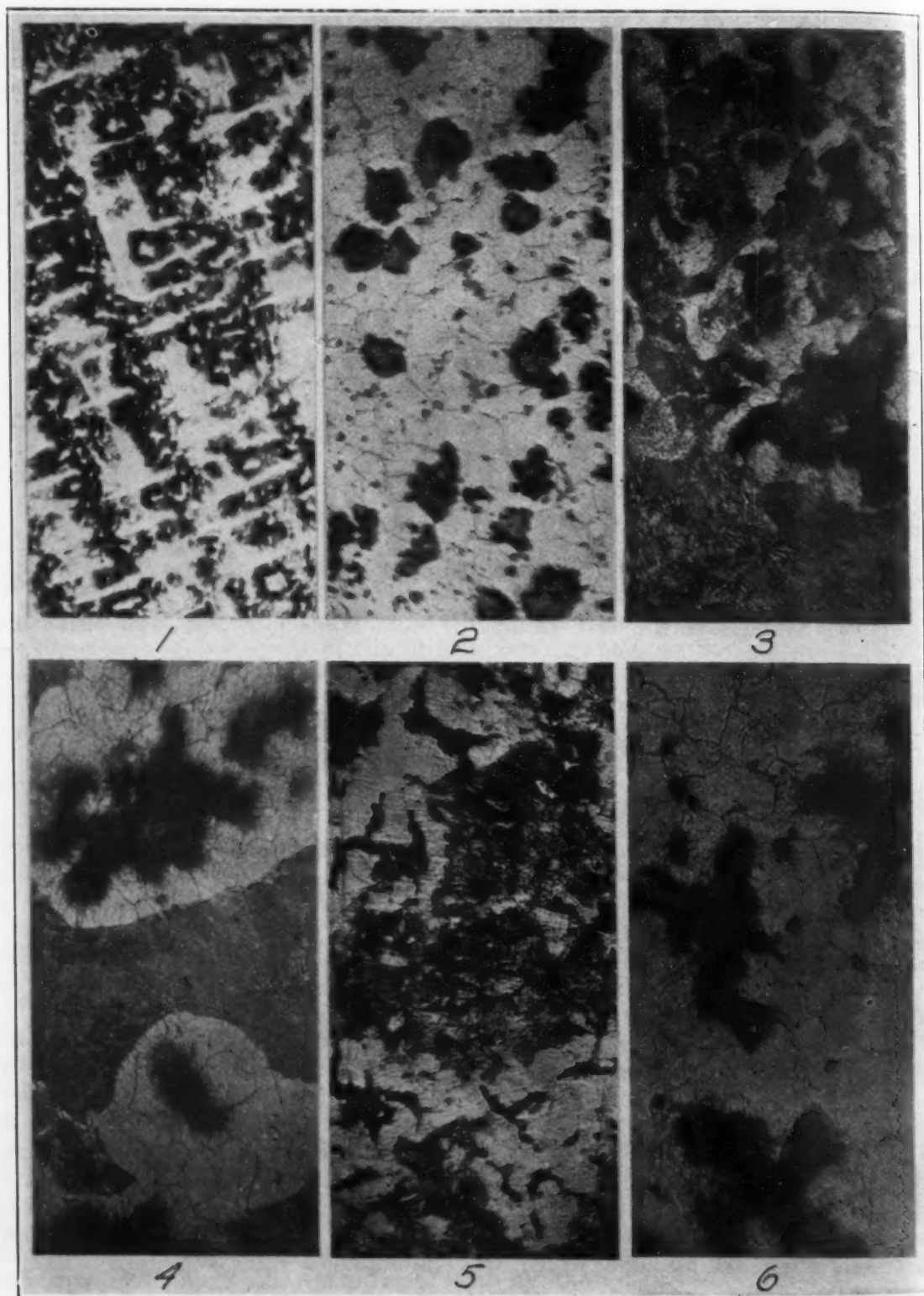


Fig. 1—Photomicrograph showing typical structure of white cast iron. $\times 150$. Fig. 2—Photomicrograph of a malleable test bar made from melt No. 1 and annealed along with a commercial run of work. $\times 75$. Fig. 3—Photomicrograph of specimen held for 4 hours at 1000 degrees Cent. and furnace-cooled. $\times 100$. Fig. 4—Specimen held for 60 hours at 1000 degrees Cent. and furnace-cooled. $\times 100$. Fig. 5—Treatment B resulted in incomplete graphitization. Considerable ferrite deposition took place around the carbon spots. $\times 100$. Fig. 6—Treatment C resulted in complete graphitization. $\times 100$.

under graphitizing conditions could have been accurately noted. On account of the small size of furnace and the large number of pieces required to complete the series, this was found impossible, since the furnace would rapidly drop in temperature on introducing the charge. The pieces were therefore charged into the cold furnace and the whole brought to temperature as rapidly as possible. It required about two hours to come to a temperature of 1000 degrees Cent., after passing the critical temperature. Three pieces were removed at a time at intervals after attaining temperature and cooled in sand, as noted in Table I. The table also includes the tension test results based upon an average of three pieces.

It will be noted that two furnaces were used in completing this series of runs. Any slight variation in the time necessary to come to heat will not

Table I.
Tensile Strength and Ductility of Specimens Treated Under Experiment A.

Time of Temperature of 1000 degrees Cent.	Strength lbs. per sq. inch	Elongation per cent in two inches	Remarks
20 mins.	84,100	0	Muffle furnace
30 mins.	87,500	0	" "
45 mins.	90,600	0	" "
1 hour	85,600	0	" "
2 hours	83,600	0	" "
3 hours	89,000	0	" "
4 hours	83,200	1.0	" "
6 hours	81,600	0	Hump Furnace
12 hours	83,900	0	" "
18 hours	86,000	0	" "
24 hours	83,800	0	" "
30 hours	83,700	0	" "
36 hours	83,400	0	" "
42 hours	82,800	0	" "
48 hours	84,400	1/2	" "
51 1/2 hours	83,100	1/2	" "
54 hours	83,400	0	" "
60 hours	81,800	1/4	" "

appreciably effect the results shown, since no comparisons are made until after five hours have elapsed. At the end of the 4 hour run in the muffle furnace, the specimens were allowed to cool normally with the furnace and similarly, after the 60 hour run in the Hump furnace the specimens were permitted to cool normally with the furnace. The average properties of these bars are shown in the following:

Time at temperature of 1000 degrees Cent.	Strength lbs. per sq. in.	Elongation per cent 2 inches	Remarks
4 hours.....	74,200	1	Cooled in and with muffle furnace
60 hours.....	76,900	4.5	Cooled in and with Hump furnace

Microscopic study of all of the specimens whose physical properties are listed in Table I brought out the following points of interest:

1. Graphitization was advanced to a remarkable extent within 20 minutes after coming to a heat of 1000 degrees Cent., and temper carbon spots were evenly distributed throughout the section. The temper carbon deposit increased slightly as the heating period was increased to 3 or 4 hours and thereafter increased time of heating had very little, if any, effect upon the carbon deposition.

2. Massive cementite was present to an appreciable extent in the

Fig. 2—
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specimen heated for only 20 minutes. As the time of heating was increased the amount of massive cementite decreased until after a heating period of 3 or 4 hours practically all traces of massive cementite had disappeared.

3. The ground mass in all of these specimens was pearlite and sorbite and in no case was there evidence of any free ferrite.

The fact that all of these specimens have this very similar structure accounts for the uniformity of tension test results shown in Table I.

Figs. 3 and 4 show the photomicrographs corresponding to the specimens whose tensile properties are listed above. It is noticeable that there is a slight deposition of free ferrite around the temper carbon in the specimen heated for 4 hours, and that there is a marked deposition of free ferrite in the specimen heated for 60 hours. This increase in free ferrite accompanied by increased carbon deposition accounts for the increased elongation of the latter specimen.

It is to be noted that the muffle furnace, due to poorer heat insulation, cooled approximately twice as rapidly as the other furnace through the critical range. The writers believe that this difference in ferrite deposition is mainly due to this variation in cooling rate rather than to the variation in time of heating at 1000 degrees Cent. This belief is held because the specimens heated for 4 hours and 60 hours at 1000 degrees Cent. and both cooled in sand showed the same structure except for the disappearance of a small amount of intergranular material in the 60 hour specimen. This point will be discussed in greater detail later in this paper.

Consideration of these results, led us to conduct the following experiments:

Experiment B. Test bars were heated at 1000 degrees Cent. for 1 hour, were cooled to 850 degrees Cent. with the furnace, were held at 850 degrees Cent. for 6 hours and then were cooled in the furnace to below the critical temperature.

Experiment C. Another bar was treated similarly except that it was finally cooled from 850 degrees Cent. through the critical range at a rate of about 4 degrees Cent. per hour.

It seemed that 1 hour at 1000 degrees Cent. was ample to start the reaction and absorb most of the massive cementite, and the temperature was dropped to 850 degrees Cent. to prevent undue grain growth. A time of 6 hours at 850 degrees Cent. was arbitrarily chosen to allow an approach to equilibrium at that temperature.

Since the number of bars were relatively few in these experiments, they were inserted in a furnace already at heat and it was possible to bring them to heat in about 20 minutes. The tensile properties of these bars follow:

Treatment	Tensile Strength lbs. per sq. in.	Elongation per cent in 2 inches
B	62,000	5
B	62,600	5
C	49,200	16.5

Fig. 5 shows that treatment B resulted in incomplete graphitization but that considerable ferrite deposition had taken place around the temper carbon spots. The ground mass was pearlite. Fig. 6 shows that treatment C resulted in complete graphitization and the product is malleable iron of good

quality as shown by the physical test. The temper carbon is not of ideal form. This point will also be taken up in greater detail later.

Experiment D. Bars were alternately heated and cooled in the furnace between the temperatures of 850 and 650 degrees Cent. for the number of times indicated.

Experiment E. Bars were alternately heated and cooled just as in Experiment D, except that the final cooling from 850 degrees Cent. was at the rate of 4 degrees Cent. per hour.

The tensile properties of these bars follow:

Number of times heated to 850 degrees Cent.	Treatment D		Treatment E	
	Tensile Strength lbs. per sq. in.	Elongation	Tensile Strength lbs. per sq. in.	Elongation
3	77,500	2	62,400	1.5
5	85,500	1.5	44,400	10
7	52,700	4	47,000	15
9	57,700	5	46,000	17.5
13	70,500	5	45,000	13.5
15	66,000	4	47,500	14.5
17	71,500	5.5	47,500	14
19	59,400	5	44,000	14

Experiment F. In conjunction with Experiment D, Experiment F was run in a similar manner except that the bars were sand cooled instead of furnace cooled, the final cool being with the furnace as before.

Experiment G. In conjunction with Experiment E, Experiment G was run in a similar manner except that the specimens were cooled in the sand. The final cool was at the rate of 4 degrees Cent. per hour as in Experiment E.

The tensile properties of these bars follow. Unfortunately the results of repetitions of heating less than 13 times have been lost.

Number of times heated to 850 degrees Cent.	Treatment F		Treatment G	
	Tensile Strength lbs. per sq. in.	Elongation	Tensile Strength lbs. per sq. in.	Elongation
13	74,600	3.0	50,000	15.5
15	71,250	2.5	51,600	14.0
17	84,700	5.5	49,100	16.0
19	82,900	6.0	47,000	17.5

Figs. 7 and 8 are photomicrographs showing typical structures obtained by the use of treatment D. It is to be noted how rapidly the massive cementite is disappearing and temper carbon is being produced due to only 3 repetitions of heating and cooling as shown by Fig. 7. Deposition of free ferrite is also evident to a slight extent.

Fig. 8 shows that further repetitions of heating and cooling produce only slightly further changes in structure, these being mainly a further elimination of free intergranular cementite. By this method we never succeeded in our experiments, in completely eliminating the last traces of massive cementite. Fig. 8 shows a structure whose ground mass is almost entirely pearlitic. It is interesting to note that previous calculation had led us to believe that if a ground mass of pearlite could be obtained we might expect a strength of 90,000 to 100,000 pounds per square inch and an elongation of 6 to 7 per cent in this material. These properties are of that order of magnitude.

Fig. 9 is a photomicrograph showing the structure obtained by treatment F. It is not greatly different from the structure of Fig. 8, except

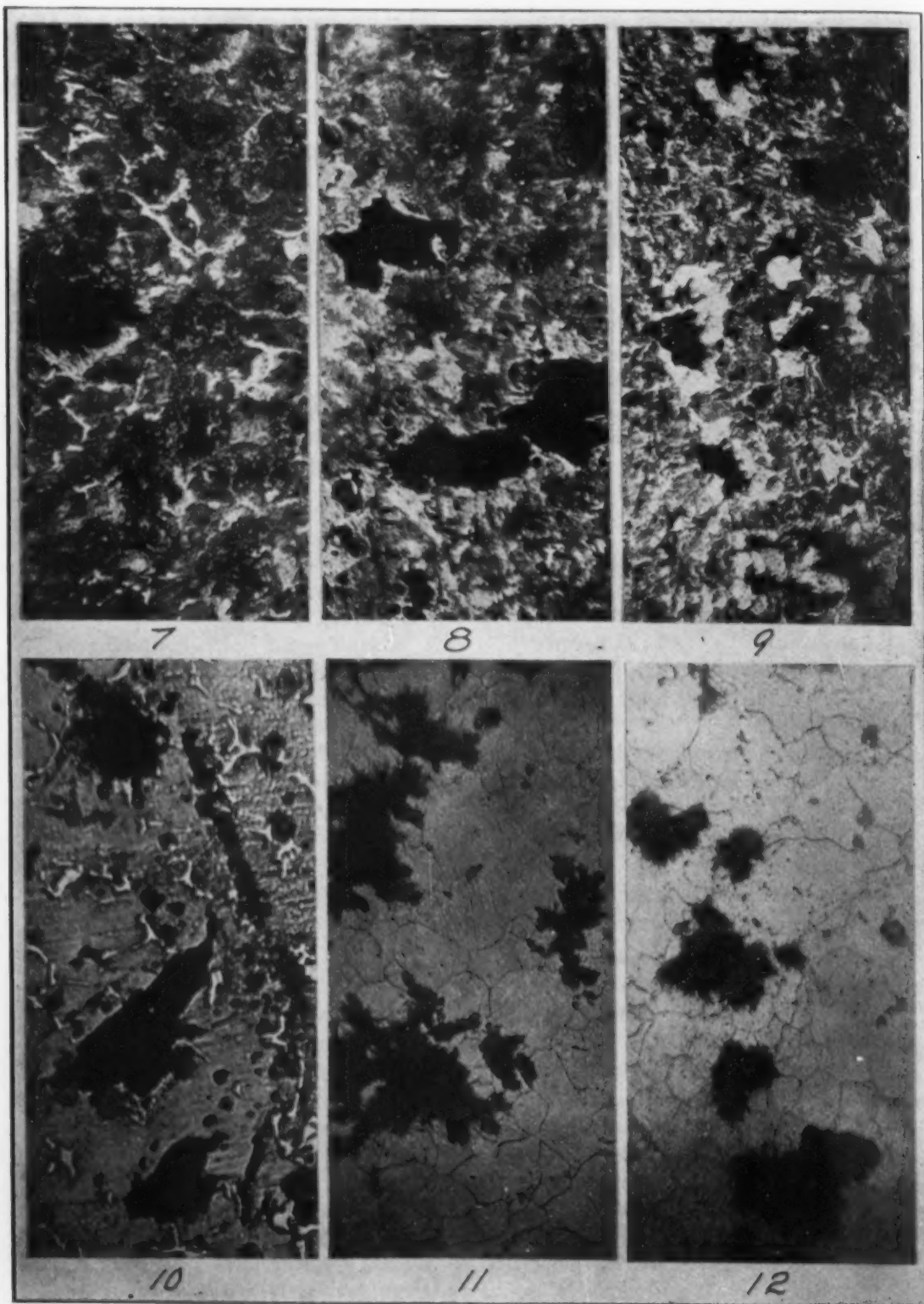


Fig. 7—Photomicrograph showing typical structures obtained by the use of treatment D, three repetitions. $\times 100$. Fig. 8—Same treatment as Fig. 7, 17 repetitions. Ground mass almost entirely pearlitic. $\times 100$. Fig. 9—Photomicrograph showing structure obtained by treatment F, 17 repetitions. $\times 100$. Fig. 10—Photomicrograph showing structure obtained by treatment E, three repetitions. $\times 100$. Fig. 11—Same as Fig. 10 with 17 repetitions. $\times 100$. Fig. 12—Photomicrograph of structure resulting from treatment G, 17 repetitions. $\times 100$.

that there is a somewhat greater deposition of free ferrite due to the final cooling having been slightly slower in this particular case, and a finer grain due to the fact that it was above the critical range for a shorter time on each repetition of heat. The finer grain probably accounts in the main, for this increased tensile strength.

The structures in Figs. 10 and 11 are typical of those obtained by treatment E. It is evident that when the repetitions are sufficiently numerous a malleable iron of excellent physical properties results. By comparing these figures with Figs. 7 and 8, it is noteworthy that a slow cooling through the critical range at the rate of 4 degrees Cent. per hour has no appreciable effect on the massive cementite. This indicates that if time is to be considered, it is advisable to absorb all massive cementite at temperatures well above the critical. Fig. 12 shows the structure resulting from treatment G and is very similar to that shown in Fig. 11 and needs no further comment.

Attention should be called to the fact that temper carbon deposited by these rapid methods of repeated heating to, and cooling from, 850 degrees Cent. is of good form. It is also to be noted that only in treatments B and C presented thus far in this paper has the form of temper carbon deposited been at all bad. In this connection it becomes interesting to present Fig. 13, which illustrates what may be done in producing variations in carbon form, although the maximum temperature used in producing this was also 1000 degrees Cent. This specimen was introduced singly into a furnace held at 1000 degrees Cent. and was brought to heat in about 12 to 15 minutes. Other specimens as already noted were brought to heat more slowly. It is possible that this furnishes a clue to the control of temper carbon form even though high temperatures are used. It is possible that the form of temper carbon first deposited has a marked effect upon the form of that deposited later. This point is being made the subject of further investigation in this laboratory.

Graphitization Theories

The writers have formulated a theory for the mechanism of the graphitizing action. To our knowledge no comprehensive theory of the mechanism of the complete graphitization of white cast iron has been presented. It has been suggested by a number of investigators that the solubility of cementite (Fe_3C) in gamma iron is greater than that of carbon (C). In this opinion the writers concur and it readily suggests a mechanism of breakdown at temperatures above the critical range. What happens on cooling slowly through the critical range is a point in dispute, for which the authors believe no comprehensive theory has been advanced. For instance H. A. Schwartz¹ indicates that the solubility of carbon in iron decreases continuously with decrease of temperature until it reaches zero at the lower critical temperature, A_1 . This necessitates that the eutectoid shifts practically to zero carbon concentration and that no ferrite separates out until A_1 is reached. This does not agree at all with the action of low carbon steel in traversing the same range. The failure of ferrite to separate from the solid solution at the point where the carbon solubility curve crosses the A_{2-3} line of the steel range is inconsistent with the known action of low carbon steels.

Archer² holds that the carbon solubility decreases continuously until it reaches approximately 0.7 per cent at A_1 and that the final decomposition

1. *The Iron Trade Review*, Feb. 3, 1921, page 353.

2. *Transactions of the American Foundrymen's association*, Vol. XXVII, 1918, page 351.

of cementite occurs below A_1 . Nothing is said as to what happens between the temperatures corresponding to the point of intersection of the carbon solubility curve with A_{2-3} and the temperature of A_1 .

Merica and Gurevich³ make the statement, "The fact that only 0.2 per cent of combined carbon was found in some specimens after annealing at high temperatures and cooling slowly in the furnace would indicate either that the graphite eutectoid lies at much lower values of carbon content than has been previously supposed, that there is at those rates of

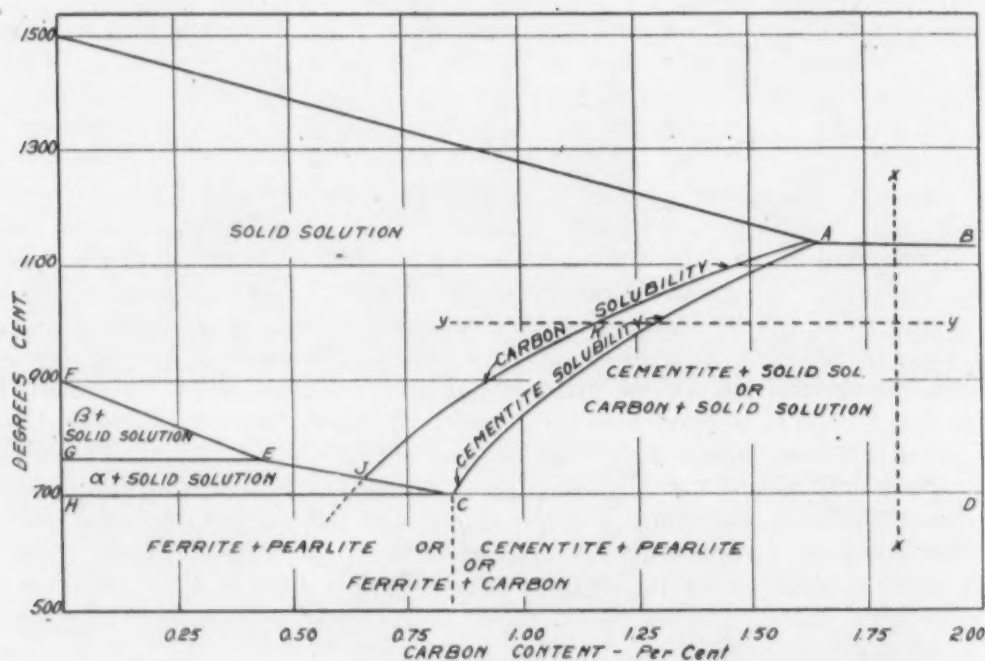


Fig. 16—Iron-Carbon Constitutional Diagram

cooling a direct precipitation of graphite eutectoid, or that there is a formation of graphite from pearlite at temperatures below that of its formation."

In both the latter references the possibility of a breakdown of pearlite to temper carbon and ferrite at temperatures below A_1 is mentioned. Such action is also inconsistent with the behavior of pearlite in steels and with the behavior of massive cementite at this temperature as well as at higher temperatures.

Origin of the Bull's-Eye Structure

In examining our furnace-cooled specimens it was noted that in a considerable number of instances there was actual contact between pearlite and the temper carbon spot; this contact being made through an opening in the ferrite ring of the "bull's-eye" structure. At temperatures above A_1 this pearlite must have been solid solution of eutectoid composition. This suggested directly that the growth of the temper carbon spot was effected by diffusion of carbon through the solid solution, and not by a diffusion of carbon through the ferrite ring. The writers can not conceive of any other method of growth, if it is granted that ferrite cannot take carbon in solution and therefore cannot act as a diffusion medium. Very often temper carbon spots completely surrounded by a ferrite ring are noted. The view

3. *Bulletin of the American Institute of Mining and Metallurgical Engineers*, July, 1919, page 1063.

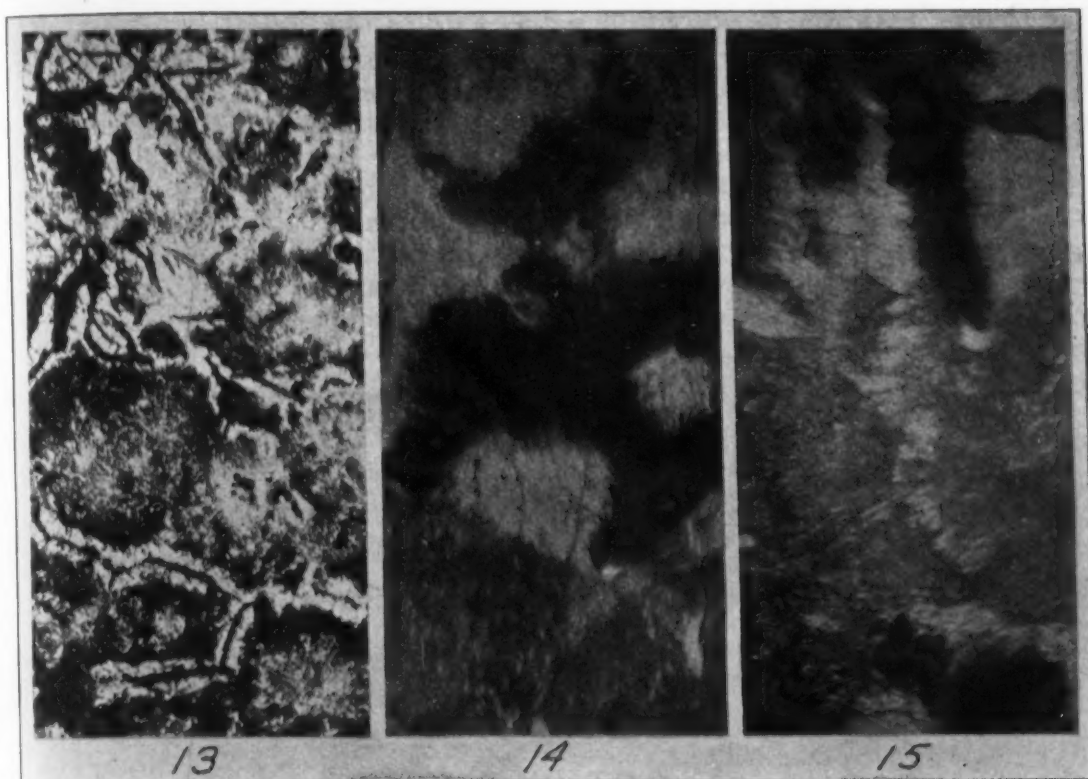


Fig. 13—Photomicrograph illustrating what may be done in producing variations in carbon form. This specimen was introduced singly into a furnace held at 1000 degrees Cent. and was brought to heat in 12 to 15 minutes. $\times 100$. Fig. 14—Photomicrograph showing contact between the pearlite and the temper carbon spot. $\times 150$. Fig. 15—Similar to Fig. 14. $\times 400$.

is from one plane only, and it must be remembered that there are numerous other planes which might have been chosen, any one of which might have shown the contact of which we speak. The authors believe that the complete enclosure of the temper carbon spot by a ferrite shell would prohibit further growth.

This idea of growth, namely that the growth takes place from solid solution areas, is in conformity with that given by Phillips and Davenport⁴ for temperatures above the critical for which they show photographic evidence. Further evidence is submitted in Figs. 14 and 15. These photographs show contact between the pearlite (which at higher temperatures was solid solution) and the temper carbon spot. In partially malleablized material in which the temper carbon deposits were elongated, it was frequently noted that such contact appeared at the extremity of the elongation. The contact is often masked in a microscopic view of a section, because carbon being softer is, during polishing, swept out to a lower level than the surrounding metal.

Theory for Complete Graphitization

If it is true that cementite or carbon going into solution in gamma iron results in identical solid solutions when equilibrium is attained, then it must follow that the simultaneous precipitation of temper carbon and Beta iron, or temper carbon and ferrite, will take place at an equilibrium temperature corresponding to that of the intersection of the carbon solu-

4. *Transactions of the American Institute of Mining and Metallurgical Engineers*, Special Paper No. 1178, January, 1922.

bility curve with the A_3 or A_{2-3} lines. In order to make these points clear these processes will be briefly traced out on the constitutional diagram Fig. 16.

Assume that we heat a white cast iron of composition X-X to 1000 degrees Cent. On passing the critical temperature the ground mass of the iron becomes solid solution and the absorption of massive cementite begins. This absorption of cementite continues as the temperature rises, due to the fact that its solubility increases with temperature. Upon holding at 1000 degrees Cent. massive cementite continues to be absorbed and at the same time carbon is being deposited since the solubility of cementite is greater than that of carbon. This process will continue until equilibrium is reached

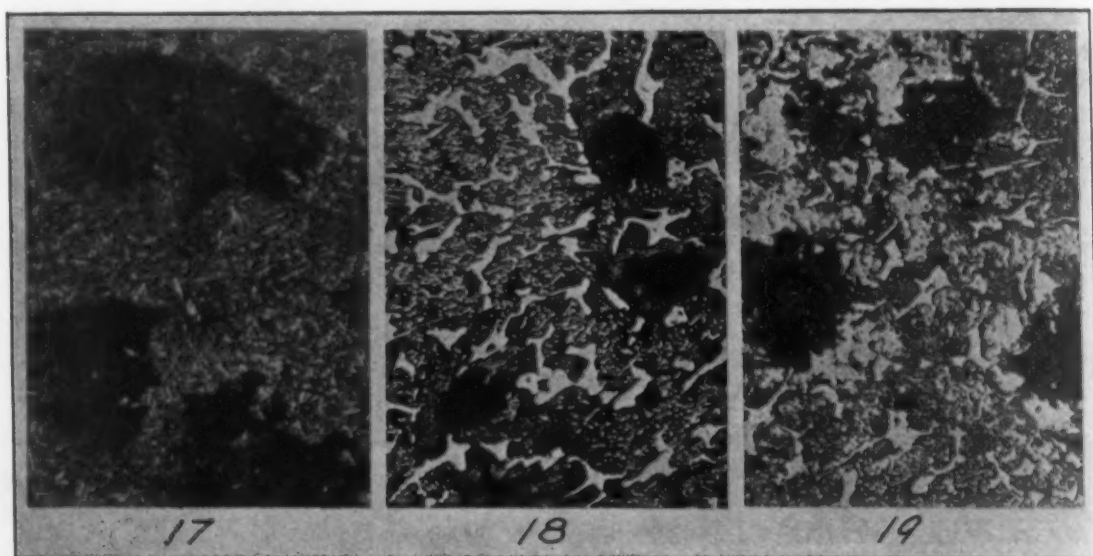


Fig. 17—Equilibrium at 920 degrees Cent. after 70 hours. Black represents temper carbon; gray and white, martensitic mixed crystals. $\times 100$. (After Schwartz.) Fig. 18—Photomicrograph of white cast iron quenched after being held at 800 degrees Cent. for 18 hours. $\times 100$. Fig. 19—Same as Fig. 18 but held for 48 hours before quenching. $\times 100$. (After Phillips and Davenport.)

between carbon and solid solution at this temperature as indicated by the point K. This process is comparatively rapid due to the high temperature. The same action would occur if other temperatures had been chosen, the only variation being a change in speed due to change in temperature.

Now, if the specimen is slowly cooled the composition of the solid solution will traverse the line KJ which means the depositing of excess carbon as the temperature is lowered until the carbon concentration reaches the value corresponding to J . At this point simultaneous precipitation of ferrite and temper carbon should begin. At this temperature it should only be necessary to slowly extract sufficient heat in order to effect complete graphitization. It is conceivable that sufficiently slow supercooling below the temperature of J would result in extending the line AJ down to the temperature of A_1 or below, and the action of graphitization continue as outlined. A number of investigators have reported graphitization continuing at these low temperatures. The potential producing graphitization would be increased by such undercooling and also continuous deposition of temper carbon would be favored by extensive and intimate contact with temper carbon already present. The only condition necessary to the actions outlined is that

at some time during the process the temperature of the metal must have been above the temperature corresponding to J .

The effect of rates of cooling more rapid than those necessary to bring about the action mentioned in the preceding paragraph would be the precipitation of ferrite in excess of that corresponding to points on an extension of the line AJ and would result in the composition of the solid solution shifting along the line JC , or nearly so, until the point C had been reached, at which time precipitation of pearlite would occur. It is common experience that too rapid cooling from these temperature regions results in some pearlite being obtained. During this shift of composition free ferrite is necessarily deposited. This might result in the complete surrounding of a temper carbon spot by a ferrite shell. In this case, just as in our previous discussion of the genesis of temper carbon spots, it is evident that the carbon spot was always in contact with solid solution during its growth.

The behavior of the solid solution as outlined, is in conformity to the known action of steels. It is a well known fact that graphitization of distinctly hypo-eutectoid steels does not occur under ordinary conditions for heat treating steels. This is due to the facts that no temper carbon contact is possible above temperature J and therefore during cooling there is no intimate temper carbon contact to favor the deposition of this form of carbon, and on cooling to lower temperatures when A_{2-3} is reached ferrite separates out of the solid solution until eutectoid composition is reached at which time pearlite is formed. It is also a well known fact that graphitization in a hyper-eutectoid steel can occur, particularly if the carbon is above 1.2 per cent. It is very probable that in this case when the steel is held at high temperatures for the long times known to be necessary to graphitize such steels, the excess cementite goes into solution causing a deposition of temper carbon and the action is entirely similar to that of white cast iron subjected to similar treatment.

The exact location of the line AJ is not known. It is generally considered that silicon causes the eutectoid composition (point C) to shift to the left. Since silicon displaces carbon in solid solution, it is probable that the point J also shifts to the left. In other words silicon may cause a decrease in the slope of both the lines AC and AJ . The fact that high silicon greatly increases the rate of graphitization seems to imply that the presence of this element increases the angle between these two lines. Such an increase in angle would bring two hastening factors into play; first, a greater difference in solubility of cementite and carbon at any temperature and, second, an increase in the temperature at which AJ meets A_{2-3} . It is possible that the point J lies on A_3 in which case beta iron and carbon would first precipitate, the beta iron later converting to alpha iron when the temperature had been sufficiently reduced.

According to this theory neither beta iron nor ferrite could form during the annealing of white cast iron until the temperature of annealing had fallen to a temperature corresponding to the intersection of the line AJ and the line A_3 or A_{2-3} . In this connection the writers would call attention to Fig. 17, taken from the paper by Schwartz already cited. This specimen was heated at 1700 degrees Fahr. (920 degrees Cent.) for 70 hours until it was thought that equilibrium conditions at this temperature had been attained. The specimen was then presumably quenched since martensitic structure is shown. Also we present Figs. 18 and 19 which are reproductions of figures 33 and 35 of the paper by Phillips and Davenport. Fig. 18 represents a specimen

of white cast iron quenched after being held at 800 degrees Cent. for 18 hours. Fig. 19 represents a like specimen quenched after 48 hours.

It is to be noted from Fig. 17 that no ferrite forms even when equilibrium is attained at 920 degrees Cent. Fig. 19 gives us a point of particular interest in that ferrite has started to appear at a temperature of 800 degrees Cent. in 48 hours. It is interpreted from this fact that the carbon solubility curve intersected the line A_3 at about 800 degrees Cent. The failure of the ferrite to appear in the specimen quenched after 18 hours is entirely due to insufficient time being given. Another photomicrograph in Phillips and Davenport's paper shows that increasing the time at 800 degrees Cent. increases the deposition of free ferrite. The slowness of the reactions in this region are strikingly indicated.

That the time for attaining equilibrium at 1000 degrees Cent. is also great is indicated by a careful microscopic study of the specimens used in our experiment A. It has already been noted that massive cementite had disappeared in from 3 to 4 hours at 1000 degrees Cent., showing that this constituent was completely in solution in this time. In specimens held at 1000 degrees Cent. for times up to 4 hours grain boundary cementite appeared. With longer periods of time beyond 4 hours this grain boundary cementite gradually disappeared until it was practically nil at 36 hours. Periods longer than 36 hours at 1000 degrees Cent. did not cause any ferrite grain boundary material to appear. This shows that the solubility value of carbon in gamma iron for this specimen was of approximately eutectoid composition, and that the equilibrium condition for carbon solubility in gamma

The explanation of the rapid rates of graphitization obtained by the alternate heating and cooling methods lies in the large angle that exists between the lines AC and AJ . On heating, the concentration of carbon in the solid solution approaches that of cementite at the temperature chosen. At this time the solubility of carbon in iron is exceeded by a certain amount. On cooling this solid solution, the excess concentration of carbon in solution over and above that corresponding to the solubility of carbon increases. During this cooling there also may have occurred an excess of carbon concentration necessary to satisfy the cementite solubility. In any case the tendency to deposit temper carbon as such is increased. This explanation is essentially the idea presented as a possibility by Phillips and Davenport at the end of their recent paper which came to our hands after our experimental work was completed. It is pleasing to us to note that other investigators were reasoning along the same lines.

Summary

In summarizing the results of this investigation it was found that

1. Cast irons having a strength of 80,000 to 85,000 pounds per square inch tensile strength with no elongation have been produced.
2. Cast irons having a strength of 60,000 to 80,000 pounds per square inch tensile strength with 5 per cent elongation have been produced.
3. Malleable cast irons having good physical properties have been produced in a 45 hour annealing time, and can be produced in even shorter time.
4. A theory for the mechanism of graphitization is presented.

In conclusion the authors wish to make the following acknowledgments: To the Iowa Malleable Iron Company of Fairfield, Iowa, who furnished us

the test bars and were ready to co-operate in every way possible. To Messrs. A. H. Swanson, R. J. Wolf and A. M. Reeder who gave considerable assistance in experimental work, and especially to W. M. Dunlap who gave such valuable assistance in all experimental work during the entire course of the investigation. His name has been properly included as one of the authors.

Discussion of Dr. Hayes' Paper

Chairman Archer: Are there any questions or any discussion on this paper?

Mr. Harder: There is one question that I think doesn't relate directly to the address, but relates to grain growth in ferrite. I have been somewhat interested in the possibility of grain growth in pure iron. For example, at a temperature of say 600 degrees Cent. I wondered if you have observed whether or not, with a given grain structure before heat treating, it would show a definite grain growth at say 600 degrees Cent.

Dr. Hayes: We have not established that point. That is an explanation of the series of points corresponding to the temperature of 600 degrees Cent. shown on this same diagram. There has been brought to our attention by some reliable firms the fact that there is a distinct change of fracture of malleableized cast iron on reheating to 600 degrees Cent. but we have not been able to detect any difference between the structure below 600 degrees Cent. or above. That has been made the subject of an extensive investigation by a number of other people. We have not tried it out. In fact, I expect it would be very difficult to try that point out with a great deal of satisfaction in partially remalleableized material.

Chairman Archer: This paper consists of two chief parts: one, the presentation of the actual test results, and the other the theoretical discussion. If you think back to the first part, there may be some questions on that. I have done some work on this problem myself, of rapid annealing, and considered all the possible ways I knew of to get good malleable in a short time, and finally I came to the conclusion that it could be done in somewhere around fifty hours. I heard this morning that there have been some commercial furnaces built which are accomplishing complete annealing, with no combined carbon remaining, in 45 to 60 hours. The malleable of very high strength, that is, above 60,000 pounds per square inch, always contains combined carbon, and apparently there is not much demand for that kind of material. The malleable people have considered the production of semi-malleableized iron as you have, and appear to believe that the product wanted is a completely annealed iron, with no combined carbon, and ductility as high as possible. I believe they are right in that judgment. I believe ductility is the quality that is responsible for the use of malleable castings.

With regard to this rapid fluctuation of temperature, that is a commercial impossibility, because malleable must be annealed cheaply, the actual cost is under one cent per pound, I think, and sometimes it is considerably under. That requires the heating of large batches

of material at one time, and large batches of material cannot have their temperature changed, either up or down, in a short space of time. Therefore, the heating and cooling must be slow.

In regard to the employment of high temperature anneals, such as 1000 degrees Cent. one important consideration to be kept in mind is the distortion of the castings, due to their softness at the high temperature. They have to be very carefully supported if you are going to heat them to 1000 degrees Cent. without changing the shape.

Dr. Hayes: I would like to ask some practical men a question as to what would be the possibility of a partially malleableized product, showing 90,000 to 100,000 pounds tensile strength and 6 per cent elongation as displacing some of the uses of steel, at the present time.

In connection with Mr. Archer's statement, I would like also to ask about packing materials in a controlled temperature, a controlled atmosphere, using counter current methods to get alternate heating and cooling at moderately rapid rates.

Chairman Archer: Has anyone any remarks on the first question? That is, as to the usefulness of a high tensile malleable with relatively little elongation. I think that demand really has to come from the consumers and the malleable people have certainly considered it and have told me, many of them, that the customers don't seem to want it.

In regard to the tunnel furnace that I spoke of, if the castings are rather intricate and thin they are apt to need packing to support them; if it is a simple shape, they can probably be stacked one on top of the other and at moderate temperatures they wouldn't warp too much. Even in that tunnel proposition, the charge probably must be fairly heavy, that is, if the trucks are say four feet across and you load them to a height of three feet or four feet—that is a pretty small tunnel—yet a mass of that weight couldn't be heated and cooled very quickly. You have to wait for the points in the charge that are the farthest away from the temperature you want. If you are cooling and you want to cool below the critical range, you have to wait until the center is down, if you are heating, you have to wait until the center is up. If you apply a rapid rate of heating, the outside will be rather higher than you want it by the time the center is up. Those are the things that make that fluctuation look rather difficult, to me, at least.

Mr. Harder: In the production of gray iron castings, we frequently get hard spots corresponding to the original condition of white iron castings. I would like to ask the speaker what temperature he would use for the annealing of those hard spots.

Dr. Hayes: If those are due to massive cementite that never has been absorbed, then it requires either a long time at the ordinary temperature of about 800 degrees Cent. or a shorter time at much higher temperatures. As I say, I am not a practical man, and I would hesitate in giving advice. We know from our photographs that on our rapid methods, after we start the slow cool, there is practically no further disappearance of massive cementite, it stays as it is. The present accepted theory is that decomposition of combined carbon takes place from the solid solution, and the massive cementite remains intact. At those temperatures, about 800 degrees Cent. the rate of absorption of massive cementite into the solid solution is slow, and its transition over, that is, its rate of precipitation, corresponding to the graphite solubility value,

is also slow, so to eliminate hard spots, the hard spots are due to not enough time at the temperature. You see that slow cooling sort of irons out all the little imperfections. Too rapid or too short a space of time at the high temperature may hurt good material.

Chairman Archer: I think in the case of gray iron the problem is much more simple, because the carbon and the silicon are very much higher, and the rate of graphitization is very much faster than in the malleable castings. You don't have to use as high a temperature, or as long a time. I think the usual practice is about 1400 degrees Fahr. I don't know just how long, possibly two hours at 1400 degrees Fahr. and slow cooling will kill those hard spots. Pistons are sometimes annealed for about 6 or 8 hours at 1000 degrees Fahr. to remove hard spots and also to relieve internal stresses which might cause distortion after machining.

Mr. Maloche: I have conducted a few experiments with the ordinary gray iron, and with the same mix and analysis and I found an anneal at 1450 degrees Fahr. for three hours could be replaced by an anneal at 1600 degrees Fahr. for 25 minutes. In running them through at that rate we got very good results, only occasionally we would get trouble with scaling, not warping,—they were very small castings, and not made for strength, but the only trouble they have is they scale occasionally. The 1600 degrees Fahr. anneal for 25 minutes seems to do the work.

Mr. Harder: I would like to ask a question about the annealing of gray iron castings where the temperature is in the range of 1400 to 1600 degrees Fahr. In some cases they have observed a marked growth in the size of the casting in that range. I would like to know if some of the men here have observed that, and at exactly what temperature that occurs, and what takes place there.

Mr. Maloche: I have noticed that at those temperatures, if the castings were carelessly left in the furnace for a longer length of time, say three or four heats, the growth was remarkable. But on a 25 minutes anneal at 1600 degrees Fahr. I have noticed no such growth. But if you leave it in the furnace for possibly two or three hours at those temperatures you will get it, as well as distortion.

Mr. Harder: That is in keeping with the experience I have had reported to me. They gave it a rather long anneal at the high temperature, and it distorted half to a quarter inch in a foot.

A RECORDING CHRONOGRAPH FOR THE INVERSE-RATE
METHOD OF THERMAL ANALYSIS*

By H. J. French

ONE of the most useful methods of thermal analysis, whereby very small arrests may be detected in the heating and cooling of metals, is that known as the inverse-rate method in which the time interval required for a definite temperature change is plotted against the temperature. Its limited application has been due largely to the expensive equipment required, but in part to the lack of suitable recording apparatus for direct plotting of curves in order to eliminate the long and tedious processes involved in their preparation from data obtained with the usual types of chronographs.

A special recording instrument for such work, designed by Rosenhain¹, has been in use for some time at the National Physical Laboratory in England, but so far as is known by the author, this instrument has not been used in the United States and no others of a similar nature are available.

The equipment and procedure employed heretofore at the Bureau of Standards² has already been described in detail and is essentially as follows:

A small slotted specimen of the test metal, mounted on a thermocouple (one wire being platinum and the other wire 90% platinum, 10% rhodium) and placed in an evacuated silica tube, is raised or lowered at a definite and predetermined rate in a tubular electric resistance furnace which is mounted in a vertical position. The platinum heating coil used is restricted to the upper end of the furnace which has a relatively large thermal capacity compared to the sample being heated and is so constructed that a gradual decrease in temperature is obtained from top to bottom. Under such conditions the rate of temperature change to which the metal is subjected is dependent upon the rate at which the specimen is moved up or down in the heating unit. This is controlled by weights acting against an adjustable flow of oil moving a plunger in a cylinder. The flow of oil is regulated by a calibrated needle-valve and the plunger is connected to the tube which contains the test specimen.

The method employed with this equipment consisted in recording on the usual type of drum chronograph the time required for a definite temperature change in the specimen while temperature measurements were taken by means of the thermocouple and a dial potentiometer. The chronograph records were subsequently "counted" and the curve plotted by hand with time intervals as abscissa and mean temperatures during the intervals as ordinates.

In order to eliminate part of the expensive equipment required and at the same time reduce somewhat the work of preparing the graphs, Merica³ proposed the use of stop watches to measure time intervals. This method eliminates the "counting" of chronograph records but it is still necessary to plot curves by hand and the ratio of time consumed in this operation to that actually employed in making observations remains quite large.

Obviously, the only satisfactory method for rapid production of in-

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1. W. Rosenhain: *Journal of the Institute of Metals*, 13, page 160; 1915.
2. *Scientific Paper* 348, Bureau of Standards, Washington, D. C.
3. *Scientific Paper* 336, Bureau of Standards, Washington, D. C.

A paper written by H. J. French, physicist with the Bureau of Standards, Washington, D. C.

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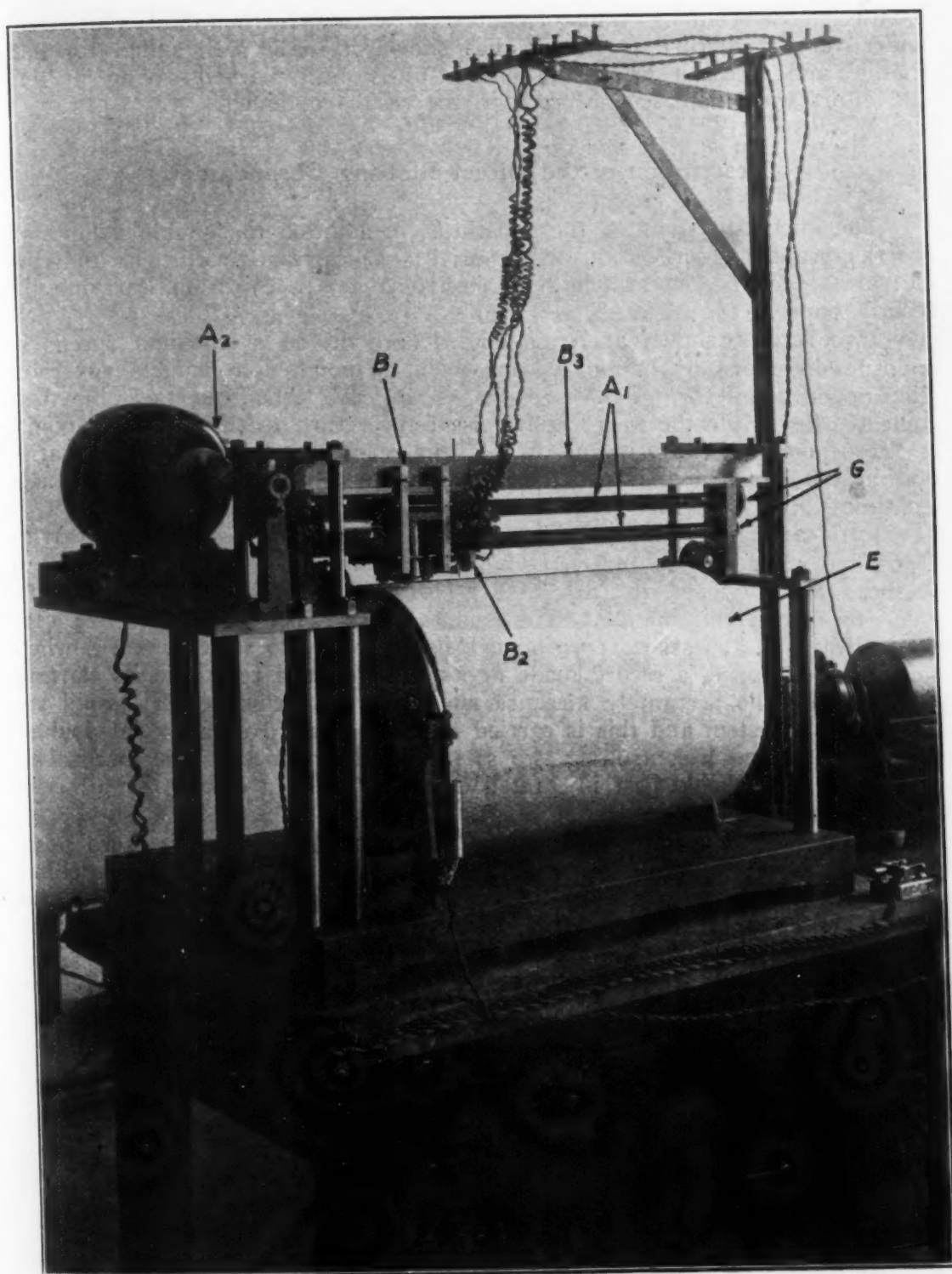


Fig. 1—Direct plotting chronograph for the inverse-rate method of thermal analysis.

verse-rate curves, particularly those covering a wide range in temperature when the plotting of 500 to 1000 points may be required as shown in Fig. 6, is by the use of a direct plotting chronograph, and to meet this condition the apparatus shown in Fig. 1 was designed. Its use for over eight

months in determining transformations in various carbon and alloy steels under varying thermal treatments has shown it to be well suited for both routine and research work and has resulted in a marked saving in time and effort with increased accuracy in the results obtained.

Description of the Direct Plotting Chronograph

The important parts of the apparatus, in addition to suitable mountings, are (a) propelling screws and motor drive; (b) carriages with pens and contact arms; (c) special switch; (d) electromagnets; (e) drum, carrying the record paper.

Two screws, shown at A_1 in Fig. 1, are driven at constant speeds in opposite directions by motor A_2 on which is mounted a suitable governor. The upper screw brings both carriages forward when engaged by their contact arms, while the lower one is used for return to their starting points or "zero positions." By means of the gear reduction shown at G and variation in the pitch of the two screws, the return of the carriages is made ten times as fast as their forward movement.

Two carriages (shown B_1 and B_2 in Fig. 1) are used. Each carries a pen and contact arms for engaging the propelling screws and runs on an overhead track, which, in each case is grooved to eliminate sideplay. In order to record continuously, time intervals, it is necessary that one carriage always be at its zero position or "base," ready to start forward, when the other is stopped, a record made of its position, and return to its starting point begun. To accurately measure such intervals requires very rapid reversal of the system and this is carried out with the aid of a special doublethrow "gang" switch controlling two sets of electromagnets. The mechanism of reversal is probably best illustrated diagrammatically, a definite set of conditions first being assumed.

As indicated in Fig. 2, carriage F is moving away from its zero position (forward), the contact arm A_1 being engaged to the upper propelling screw. At the same time carriage R is returning to base at ten times the speed at which F is going forward. It will also be noted from Fig. 2 that the "reversing magnets" K_1 and K_2 are so arranged that when carrying current they throw the contact arms of both carriages against the "return screw," while when no current passes through their respective circuits the springs S_1 and S_2 hold these arms in contact with the "forward screw." It is therefore, possible by breaking the circuit k_2 and closing k_1 to reverse the system so that carriage R moves forward from its base and F returns. This change may readily be handled by a doublethrow switch, the moving arm of which travels through a small arc. By adding to it the necessary contact points it is possible to excite additional magnets operating auxiliary equipment, including the recording pens, which will give a record of carriage or pen positions at any instant that reversal of the system is desired.

The return of the carriages is quite rapid, so that the stops placed at their base positions are subjected to considerable impact. Tapered pins are used to raise their contact arms into a neutral position to prevent "stripping" the threads of the screws and there is, therefore, a decided tendency for the carriages to rebound. To avoid this and insure identical zero pen positions after each return additional magnets are placed at the base stops and hold the carriages in place until they again start forward. Thus six magnets are controlled by the special doublethrow "gang" switch which

is thrown from X to Y or Y to X, depending upon its position at the instant the operator desires reversal.

As the moving arm of the switch travels from Y to X, for example, pen P_2 is depressed and a record of its base position obtained. Because of the small width of contacts controlling the pen magnets the circuit p_2 is quickly broken and the pen raised, thereby preventing it being dragged along the paper. Simultaneously circuits k_2 and z_2 are opened, resulting in the

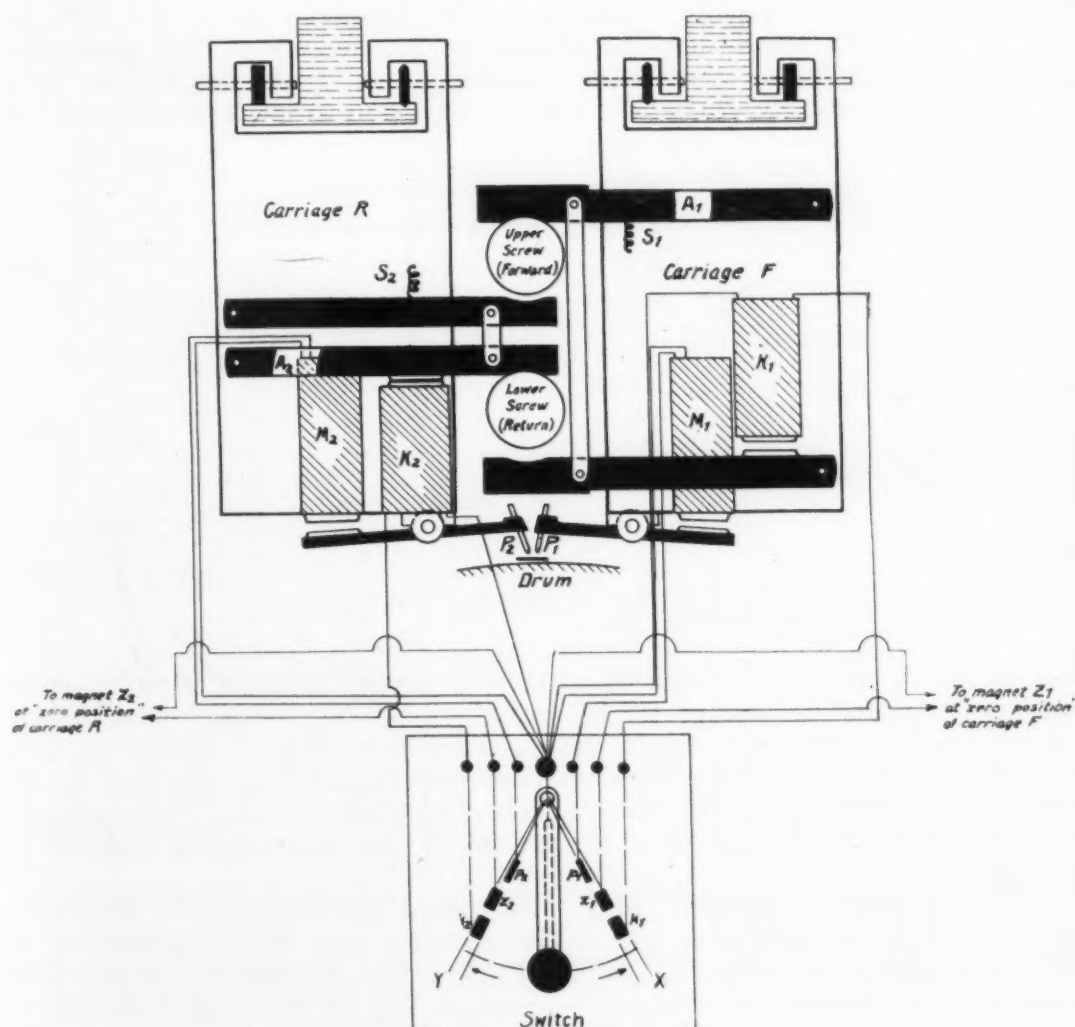


Fig. 2—Diagram showing fundamentals of design and operation of the direct plotting chronograph.

release of the carriage R by the base magnet Z_2 at the same time that the contact arm is released by magnet K_2 and pulled by spring S_2 against the forward screw. When the moving arm of the switch reaches contacts z_1 and k_1 , the zero magnet for carriage F is excited and simultaneously the contact arm is thrown from forward into reverse. At the same instant the pen P_1 is depressed by its magnet and then quickly raised by the breaking of the circuit at p_1 . This entire cycle of change, requires less than one-fifth of a second under ordinary conditions.

To plot time intervals as a function of temperature by means of the mechanism just described does not offer any special difficulties. Instead of a drum rotating at a constant and predetermined speed, such as is em-

ployed with the usual type of recording chronograph, one is required which can be moved a fixed distance whenever desired. If the distance between the line of travel of the two pen points is equal to x (Fig. 3) and the first time interval recorded in any run is made with pen B then it is not necessary to move the drum carrying the paper until after A has recorded the second interval. It should then be moved in the direction S a distance equal to $2x$. This brings the first point of the curve, b , to the position b^1 , the second point, a to a^1 and the third point which is again recorded by pen B over the position originally occupied on the paper by point b . The control of the drum movement can readily be handled by a ring gear and a simple mechanical device which is operated by an electromagnet, as shown in Fig. 1. As the two pens alternate in recording time intervals and rota-

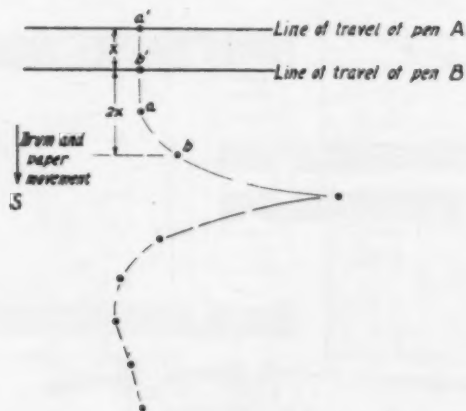


Fig. 3—Relation of drum movement to pen positions.

tion of the drum is only required after each second interval, control of the latter may be added to the special "gang" switch by placing an additional contact point on that side where the carriage B of Fig. 3 is thrown from forward into reverse. Thus time intervals are recorded as abscissae by the movement of pens along the axes of the propelling screws while temperatures are recorded as ordinates by means of the intermittent rotation of the drum.

The procedure employed with this special chronograph is similar to that used with the ordinary type. The operator sets the potentiometer at successive values of e. m. f., differing by equal increments, usually 0.02 millivolt, but instead of pressing a contact key at the exact instant at which the galvanometer coil passes through its null position, throws the special switch which reverses the entire system.

Typical Curves Obtained

Reproduction of typical curves obtained by the use of the apparatus are given in Figs. 4, 5 and 6. Relatively minute thermal arrests, such as the A_2 transformation in pure iron (Fig. 4) which are not readily observed except when using accurate methods, are clearly shown. The characteristics of different transformations are also well preserved, as is illustrated in Fig. 6 where both "sharp" and "rounded points" appear. Likewise, equally good results are obtained when using rapid (Fig. 4) or slow (Fig. 6) rates of temperature change.

The curves are not produced automatically and are, therefore, still

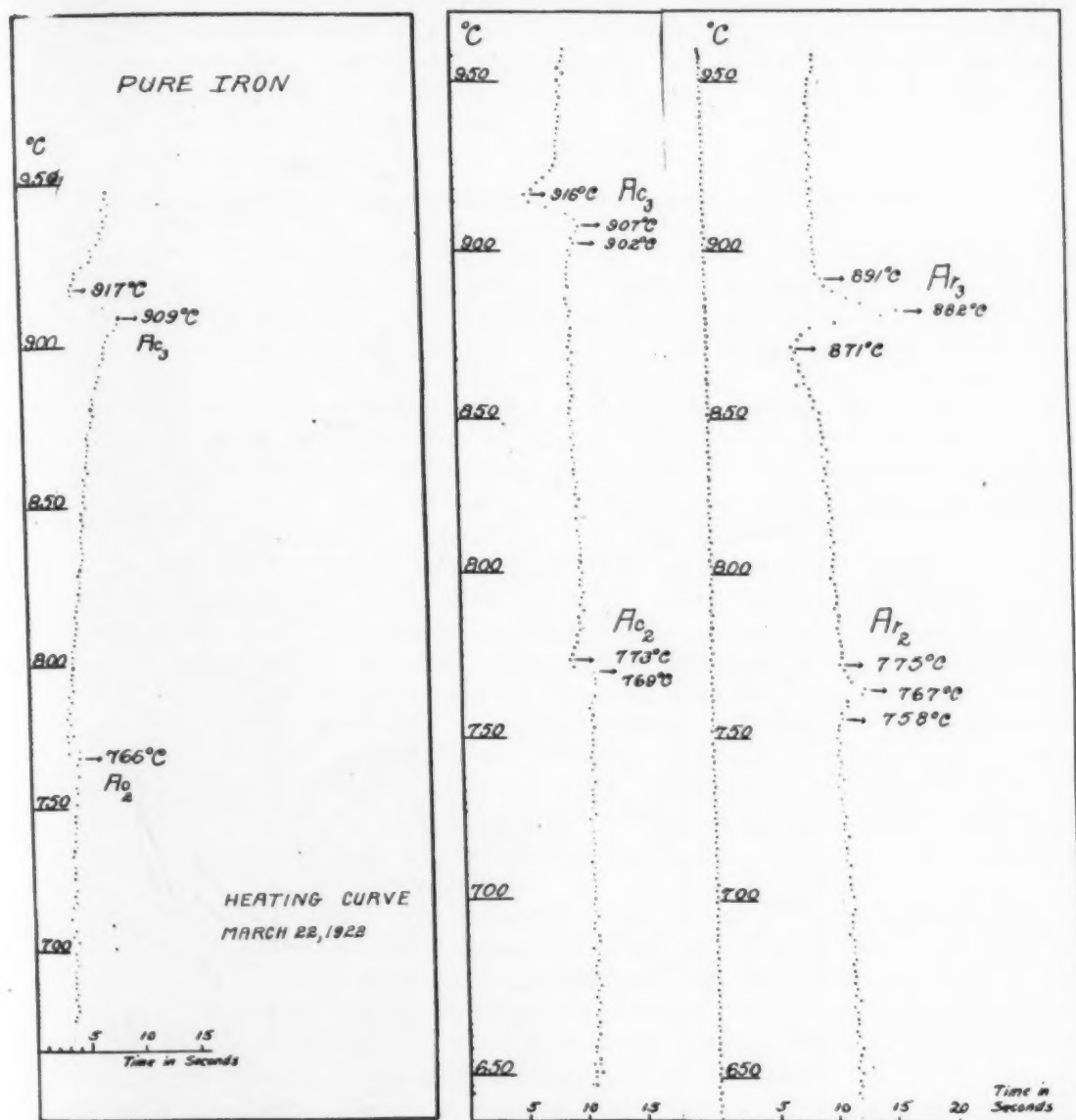


Fig. 4—Heating curve of pure iron obtained with the direct plotting chronograph. About 25 minutes required for the "run." Reproduction about one-third size. Fig. 5—Heating and cooling curves of copper steel containing carbon, 0.06 per cent; copper, 0.24 per cent. Reproduction about one-third size.

dependent upon the careful work of an operator. They are, however, less susceptible to errors arising purely from the "human element" than are curves prepared by methods employed in hand plotting as the "counting" of chronograph sheets containing several hundred observations and the placing of values so obtained upon finely divided cross section paper demands most painstaking and careful work for the elimination of errors.

Long and short readings, resulting from delay in throwing the switch as the galvanometer passes its null position, are not eliminated but are definitely shown by reason of the fact that the resulting points will be at equal distances and on opposite sides of the true curve. One of two examples of this are contained in Fig. 6. However, errors introduced in the plotting are avoided.

A desirable feature of the curves is the check obtained on the base

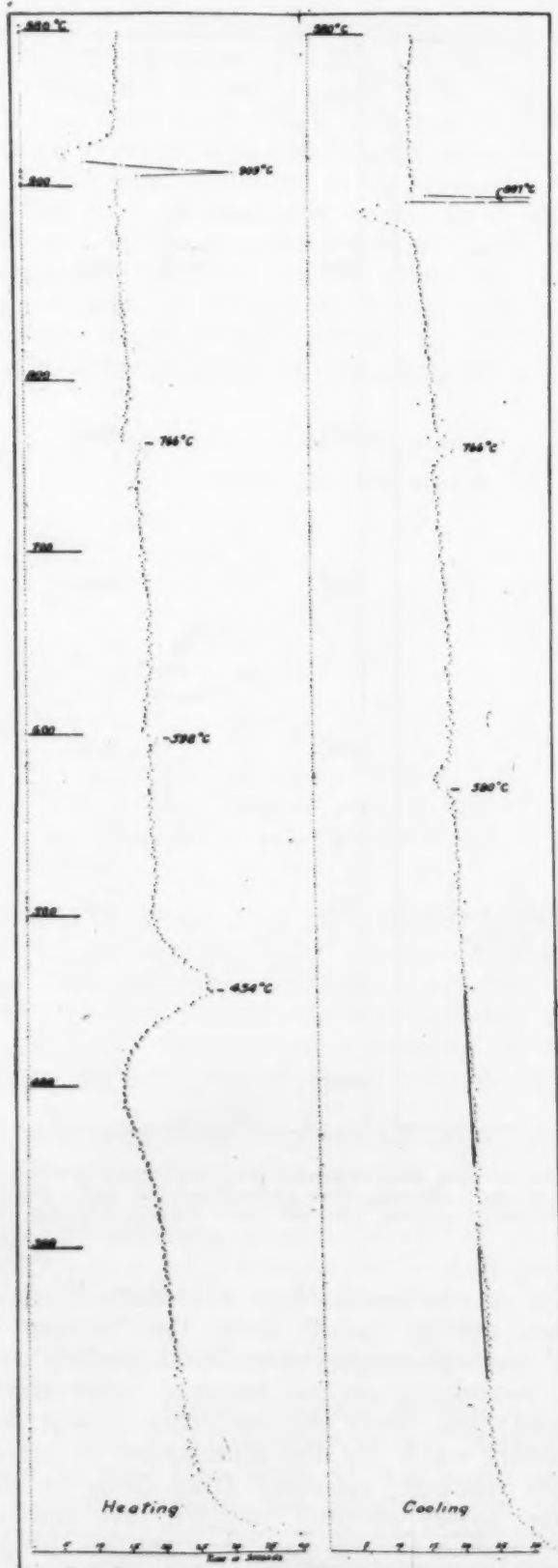


Fig. 6—Heating and cooling curves of electrolytic iron remelted under an atmosphere of nitrogen in a zirconium crucible and to which a small proportion of calcium has been added. Reproduction about one-fourth size.

position of both pens prior to recording each time interval. This was inadvertently introduced with the use of the reversing switch and equipment previously described, but is of considerable value in preventing introduction of errors due to a changing base line brought about by loosened carriage or pen parts or other causes.

Discussion of Constructional Features of the Instrument

Because of the varying magnitude of thermal transformations a high speed return of the pens is necessary. Usually long arrests are followed by very short intervals and a condition may obtain where insufficient time is allowed for one carriage to return to its base position before it is again required to start forward to record a subsequent interval. In general a ratio of 10 to 1 is sufficient though one or two cases have already been encountered where this was not so. However, it is questionable whether any additional information of value would be obtained by following completely such extremely large thermal effects, though they may readily be recorded by increasing somewhat the speed ratio referred to.

One of the important features of the equipment is the special switch, several types of which have been tried, as shown in Fig. 7. Type A was used originally and was generally satisfactory except for the rapid burning of the contacts which required considerable attention to insure satisfactory operation. A knife switch, such as type B, was tried but due to excessive arcing and inconvenience in operating it, was discarded. This type was replaced by C which proved to be the most desirable and has been adopted. It was recognized, however, that the early difficulties encountered were due to the relatively high current necessary for operating the magnets, as originally constructed and that by rewinding for lower current such undesirable effects would be largely eliminated.

The recording pens are different from those ordinarily employed. A two-color typewriter ribbon is stretched along the line of travel of the pens, which consist of small steel rods, rounded at the ends, and mounted in suitable holders. When depressed by their magnets, the pens strike the ribbon, which is close to the paper, leaving a small round dot. Thus the use of fountain pens or other types containing liquids which are not well suited to the service requirements in this instrument and which ordinarily require a good deal of attention, is avoided.

The original apparatus shown in Fig. 1 was purposely made larger than necessary in order that adjustments and such changes as might be desired could more readily be made in the laboratory but there is no reason why a second model should not be made smaller and portable. The width and diameter of the drum may be reduced. Also, the carriages, propelling screws and many of the mountings are larger than required, but an adequate driving force must be retained as constant speed of rotation of the screws is one of the essential features of satisfactory operation. Engaging the contact arms is accompanied by impact, and results in sudden changes in load which must be absorbed by the motor and governor without noticeable speed change in the recording pens.

It is not necessary to restrict the use of the apparatus to the special furnace previously mentioned, as entirely satisfactory curves for ordinary purposes may be obtained with any heating unit in which a moderately uniform rate of temperature change can be produced and under such conditions determination of transformations may be made in a very short time. The curve

shown in Fig. 4 was obtained in about 25 minutes after the test sample was prepared by heating it in air in a small and inexpensive resistance furnace.

Certain modifications or additions to the original apparatus shown in Fig. 1 are now in progress. These include the installation of a simple mechanism for moving the typewriter ribbon with the drum in order to distribute the wear resulting from pens repeatedly striking within a narrow zone; a shifting device for more readily changing the record from black to red, instead of interchanging the positions of spools carrying the two-color ribbon; a "base shift" for the drum so that heating and cooling curves may be obtained side by side instead of as in the original apparatus, one over the other unless the paper position was changed.

The instrument described serves the same purpose as that in use in the National Physical Laboratory previously referred to. However, two pens are used as suggested by O. F. Hudson⁴ thereby obviating the necessity of providing compensation for the time required for a single pen to return to its base position. Also, the use of a typewriter ribbon and solid steel bars for producing the records gives much less trouble than any type of pen already devised for the use of liquids in producing curves by a series of detached markings, and the use of a special doublethrow "gang" switch, which is not much more troublesome to operate than a key, has simplified the electrical control. It is believed the new instrument is more simply and, therefore, more cheaply constructed.

The author takes pleasure in making acknowledgement to J. Ludewig, mechanic, instrument shop, Bureau of Standards, who contributed so largely to the success of this instrument by working out the mechanical details from incomplete drawings and sketches containing principally the fundamental features of design; and to Misses I. Wymore, assistant chemist, and M. Preble, senior aid, who have handled the laboratory work in connection with the trial of the apparatus.

4. See footnote No. 1.

THE STRUCTURE AND RELATED PROPERTIES OF METALS

By Henry S. Rawdon

Abstract

This paper dealing with the structure and related properties of metals is divided into four main parts. The first part is the introduction which outlines in some detail the purpose of the paper stating that in order for one to be familiar with the reasons for variations in the properties of metals under different treatments a knowledge of the structure of the material is indispensable. Nonferrous as well as ferrous alloys are discussed.

The second part dealing with the structure of metals, develops the topics of macrostructure, conditions affecting structure, chemical composition, temperature, grain growth, phase changes and the working of metals.

The third part develops the effects of the structure of alloys upon their properties. The topics in this division deal with hard and soft constituents, soft ductile constituents, orientation of test specimen with respect to material under test, coarsely grained metals, physical state of microscopic constituents, chemical properties, solubility of tempered steels and corrosion.

The last part discusses the applications of the microscopy of metals. The author discusses the relations of microscopy to the heat treatment of metals showing that microscopy is a very valuable aid in the control of metallurgical operations and products. In the investigation of materials which have failed in service the microscope has proved invaluable. A number of examples of the deterioration of metals and alloys in service are given.

Introduction

TO ANYONE interested in the WHY and WHEREFORE of the behavior of metals, for example, the reasons for the variations of properties under different treatments or the detection of evidence leading to an explanation of the deterioration or failure of metals in service, a knowledge of the structure is indispensable. This line of study and investigation is probably the most fascinating of all the various subjects which we group together under the heading of, *metallurgy*. However, if any method or line of investigation is to hold its own, particularly in a commercial laboratory, IT MUST PAY ITS WAY and it is, therefore, the practical value of the microscopy of metals that has been emphasized in the following discussion. Many of the illustrations used have been purposely chosen from other alloys besides steel in order to emphasize the fact that steels form only one group in the general classification and are subject to the same laws as are all alloys. Largely on account of the preponderating industrial importance of steels, the idea has formed in the minds of some, particularly those whose work deals with only a few types of materials, that the convenient distinction usually made

A paper presented before the Philadelphia chapter of the society. The author, Henry S. Rawdon, is physicist with the Bureau of Standards, Washington, D. C.

between ferrous and nonferrous alloys as a convenience for classification and discussion is a very real distinction and, as a result, steels are apt not to be regarded in the same light that *alloys* are.

The physical properties of an alloy are much more closely related to the minute structure of the material than they are to the ultimate chemical composition. Today no one questions the value of chemical analysis in metallurgical work but the metallographic examination when properly interpreted may be of far greater value than the chemical, for example, in explaining the properties and predicting the uses of the finished product. The nature of the various microconstituents comprising the alloy and their relative size and distribution, the occurrence of extraneous substances or *inclusions*, the structural effects of thermal and mechanical treatment together with other features revealed by the examination are factors of supreme importance in determining the properties of the material.

All tests of metals are for the general purpose of determining the suitability of the material for some specific use, the mechanical properties are therefore in many cases, the ultimate criteria. As in the case of chemical analysis the metallographic examination can be made of inestimable service in mechanical testing. The selection of specimens may determine absolutely the validity of any conclusions drawn from tests. Not only may the small test specimens be properly taken so as to represent the larger mass of metal but the results obtained in the test may be most properly interpreted in terms of the structure of the material and for purposes of comparison it is necessary the materials be in the same structural condition.

A knowledge of the chemical composition is essential to a full understanding and interpretation of the structural condition of any metal or alloy and to a somewhat lesser extent mechanical testing is also. Conversely, a knowledge of the structural condition supplements and explains the results of the other two methods of testing. All three are mutually interdependent and necessary for a full understanding of the properties of any metal.

Structure of Metals

The term *STRUCTURE* when employed with reference to metals and alloys is used in a somewhat restricted sense. The metal microscopist ordinarily does not use this term to include such structural features as the minute crystalline structure, the atomic arrangement and such other fundamental features of matter as may be revealed by suitably refined means. The term is generally used to include those features, which can be revealed by the use of an instrument having no greater refinement than that of the modern compound microscope.

Macrostructure

In exactly the same way that a knowledge of the anatomy of the human body must be used as a background into which to fit the information gained by a study of the minute features of the various tissues which make up the body, just so is the knowledge of the gross structure of metals and alloys as gained from a macroscopic examination very helpful and necessary in understanding properly the minute features revealed by the microscope. A discussion of the macrostructure of metals could easily constitute the basis of an entire evening's talk. A few typical illustrations only will be considered.

The principal use made of macroscopic examination of steels is probably the detection of nonhomogeneity of composition, the well-known *SULPHUR PRINT* being the most familiar illustration. Etching of some kind is usually



Fig. 1—Macrostructure of forged steel (portion of shrapnel shell) revealed by etching a longitudinal section with cupric chloride (Stead's reagent). $\times 4/5$. Fig. 2a—Specimen of oxyacetylene welded steel plate etched with aqueous solution of ammonium persulphate. Fig. 2b—Same as Fig. 2a, etched with aqueous solution of copper ammonium chloride. Fig. 2c—Same as Fig. 2a, etched with 2 per cent alcoholic nitric acid. Fig. 2d—Welded steel plate, similar to Fig. 2a, illustrating overheating of the plate, etched with ammonium persulphate. Fig. 2e—Cross-section of a bar of segregated steel, etched with ammonium persulphate. These photographs illustrate the advantages of the use of ammonium persulphate as an etching reagent. All photographs full size, excepting Fig. 1.

a prerequisite for revealing nonhomogeneity, one of the well-known cupric reagents is often employed for the purpose (Fig. 1). The use of such a reagent has an additional advantage in that it often reveals many things concerning the previous history of the material, particularly its mechanical working. Phosphorus diffuses in iron or steel with extreme slowness and hence the streaky appearance caused by the non-uniform distribution of this element persists throughout the period of mechanical working of the material and thus records the story of the deformation the metal had to undergo. This is often of advantage in determining whether certain defects had their origin before, during, or after the process of mechanical working. In other alloys, similar persistent features may tell the same story.

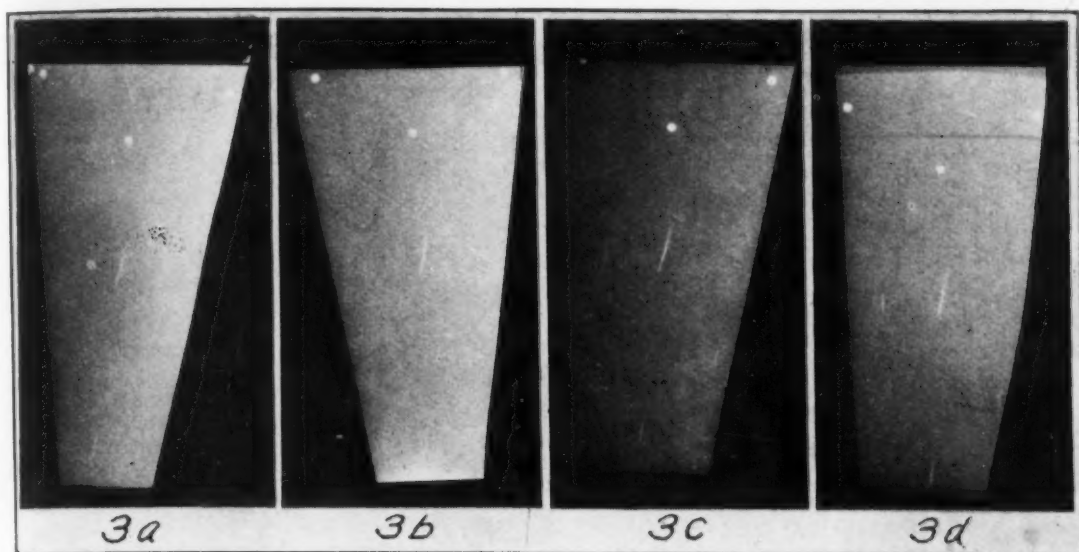
Deep etching of steel is an easy and convenient method for revealing many of its structural features. Such an etching often tells much concerning the chemical homogeneity, the crystalline condition, and the physical soundness of the material. A method which has recently been described by the Bureau of Standards for revealing crystalline heterogeneity of iron and steel depends upon etching by means ammonium persulphate solution. (Fig. 2). This has the advantage that it does not roughen the surface as deep etching does, yet reveals the crystalline condition in a very striking manner. Its use for copper alloys has been recognized for some time.

For revealing the physical unsoundness of metals, special methods are often necessary. Thus the porosity of aluminum alloy castings may often be detected by soaking the sectioned and polished specimen in highly colored alcohol (picric acid is admirable for the purpose) quickly wiping and drying the surface of specimen and then permitting the alcohol contained within the tiny cavities to exude and evaporate leaving a colored spot which will make the location of each internal cavity or pore.

Radiographic examination has been successfully employed for the examination of the physical condition of interior of metals if specimens are of suitable size. The detection of additions of lead alloy or similar material to full cavities in aluminum alloy castings may be made by this means. For steel, the method had been successfully used in locating internal defects, such as FLAKES (internal discontinuities) as well as grosser imperfections such as blow holes. In general the specimen, if steel, must not exceed $\frac{1}{2}$ inch in thickness. The method will probably never be used as a routine means of examination on account of its cost, danger of operation, and its inherent limitations. Fig. 3 shows an application of its use in following the persistence of certain internal defects during a series of treatments used for the purpose of eliminating them.

A special method which is very successful in locating cracks or other discontinuities which appear on the surface of a steel specimen is a magnetic one. The polished specimen after being magnetized is bathed in a light oil (kerosene) carrying fine iron dust in suspension. This method has found practical every day application at the Bureau of Standards in the inspection of gage-blocks after the hardening process. A great deal of time was saved in this way by rejecting specimens showing surface cracks by this means before subjecting them to the tedious lapping operation (Fig. 4). It has also been used successfully in locating interior fractures in rolled and forged steel products such as rails. These internal fractures may be revealed by other means, such as deep etching, but the magnetic method appears to be the only suitable one which does not alter, in any way, the character of the surface of the specimen.

The mechanical condition of a metal, that is, its state with respect to



Figs. 3a-3d—Defects, "flakes," in forged gun steel revealed by radiographic examination. Approximately $\times \frac{1}{4}$. A radiograph of the specimen was taken after each of the treatments listed below. The steel plate $\frac{1}{4}$ -inch thick, containing three holes (white spots in radiographs) drilled partly through for reference points was placed so that the direction of the X-rays coincided with the plane of the defect. Each white line in the radiograph represents a "flake." Fig. 3a—Forging, as received. Fig. 3b—Same as Fig. 3a after annealing for 30 minutes at 900 degrees Cent., furnace cooled. Fig. 3c—Same as Fig. 3b, heated 30 minutes at 900 degrees Cent. and quenched in oil. Fig. 3d—Same as Fig. 3c, heated 30 minutes at 1050 degrees Cent., was quenched in oil. The successive radiographs indicate the persistence of the defects after the thermal treatments given the material. Exposure: 9-inch spark, 2 millimeters, 7 minutes.

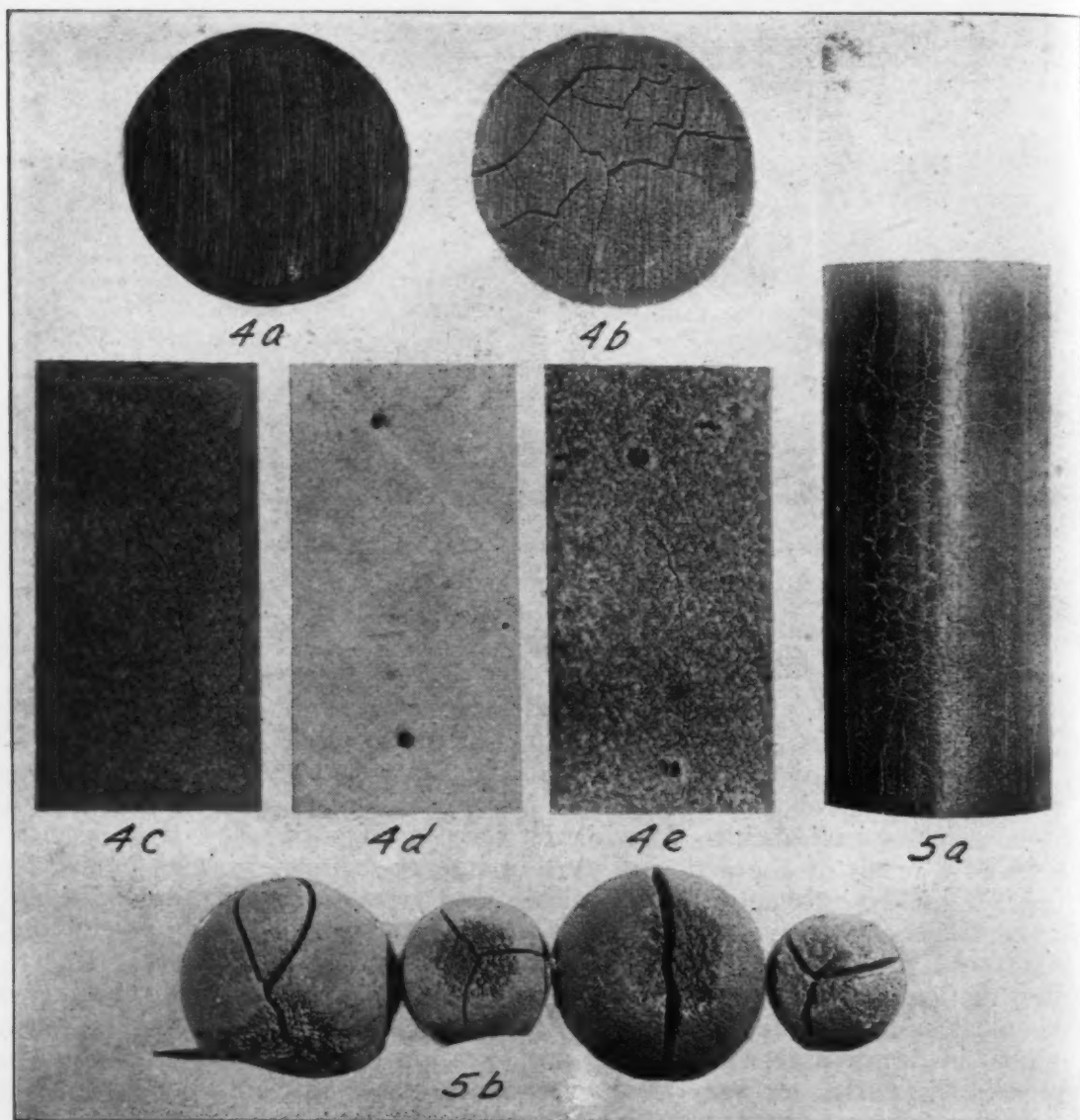
internal stresses has much to do with the stability of such material in service. Often, as a result of the action of certain intense etching reagents, materials which are highly internally stressed either as a result of mechanical work or thermal treatment received can be made to fail in a manner closely resembling what would probably have occurred spontaneously later in service. Fig. 5 shows the behavior of two types of materials after etching to reveal the mechanical nonuniformity. This defect termed SEASON CRACKING is most common in brass and some other copper alloys but the same conditions may exist in steel after very severe treatment either mechanical or thermal.

Conditions Affecting Structure

The principal conditions which affect and determine the structure of metals are, chemical composition, temperature, and mechanical treatment; chemical composition being doubtless the most important.

Chemical Composition

To discuss adequately the structural variations due to composition would necessitate a lengthy review of the PHASE RULE. A brief reference to the various typical copper-zinc alloys will suffice as an illustration. Fig. 6 shows the structure of the alloys corresponding to the different structural fields of the copper-zinc constitutional diagram. The structural changes corresponding to variations in the relative amounts of the two component metals are very evident. One fact which is very plain from the micrographs, though indicated also in the diagram, is the alternation of homogeneous (one constituent) and heterogeneous (two constituent) structural fields. This, of course, is merely one of the observed facts which are summarized in the concise statement familiar to us as the phase rule. This fact is often of importance in deciding whether certain features observed in the structure of an



Figs. 4a-4e—Physical unsoundness of steel revealed by magnetic examination. Fig. 4a—Roughly polished surface of a precision gage block. $\times 1\frac{1}{2}$. Fig. 4b—Same as Fig. 4a magnetized and bathed in kerosene containing fine iron dust in suspension; a network of fine "hardening" cracks is revealed. $\times 1\frac{1}{2}$. Fig. 4c—Section of steel from head of a rail containing internal fractures, revealed by method of Fig. 4b. $\times 3$. Fig. 4d—Same specimen as Fig. 4c after locating the defect by a punch mark at each end. After removing the iron dust no trace of the discontinuity could be seen. $\times 3$. Fig. 4e—Same specimen as Fig. 4d retreated as given in Fig. 4b. $\times 3$. Fig. 5a and 5b—Mechanical nonuniformity of wrought metals revealed by deep etching. Fig. 5a—Section of a 1-inch manganese bronze rod etched with an acidulated aqueous solution of mercurous nitrate (65 grams, mercurous nitrate, 15 cubic centimeters, nitric acid per liter). $\times 1$. Fig. 5b—Hardened steel balls which split open when deeply etched with concentrated hydrochloric acid.

alloy are due to traces of a second constituent or to other causes. A more familiar illustration of the variations in structure caused by slight composition changes in a binary alloy is that of annealed carbon steel as shown in Fig. 7. The range covered by these micrographs is only a relatively small part of the complete diagram, the variations in structure are very pronounced, however, although we are dealing with the same two phases throughout. The pronounced difference corresponding to relatively slight changes of composition render the estimation of the percentage composition from the appearance of the structure very easy and rather accurate—a valuable sup-

plement to chemical analysis by which may be shown variations in composition which the ordinary methods of sampling do not permit chemical analysis to detect. This application of the microscope in the study of segregated steel is familiar to all.

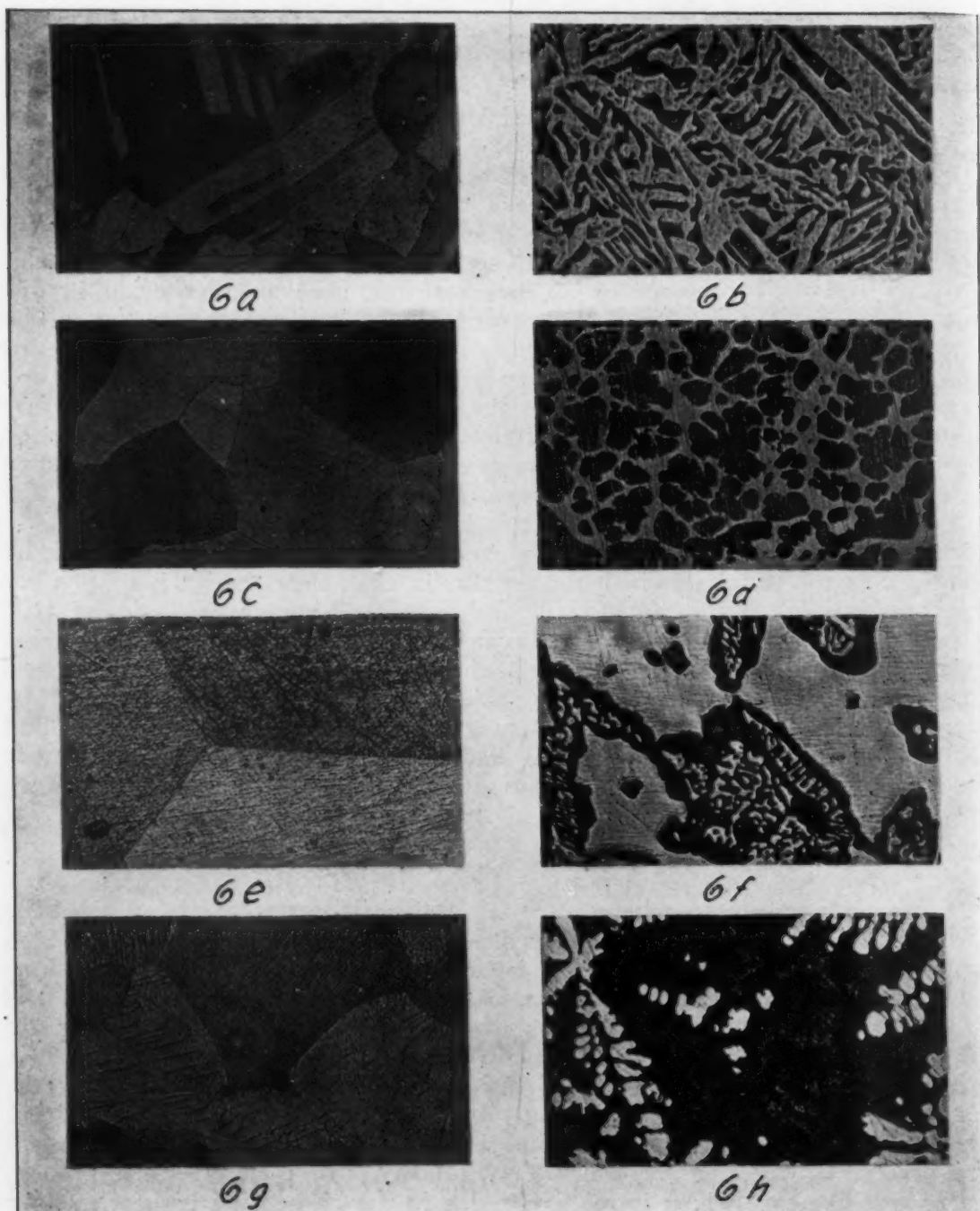
It often happens that metals and alloys show certain features of structure which are best described as being due to small inclusions of foreign material. Such enclussions, however, are often foreign only in the sense, that they are nonmetallic. They are a necessary result of the metallurgical process used for the preparation of the material. The everpresent slag of wrought iron is an example. Such slag threads are characteristic of this material and their presence or absence is often used as a criterion in disputed cases in deciding upon the nature of the material. The foreign inclusions may also result from additions made to the metal in course of preparation for improving its properties by some chemical reaction, for example, deoxidation and similar reactions. The products of the reaction are often retained in part by the metal after solidification and form a characteristic feature of the structure. Fig. 8 shows an inclusion in steel which resulted from an addition of titanium to the metal. The pink color and shape are quite characteristic of inclusions of this kind.

Some of the foreign inclusions are under certain conditions decidedly injurious to the metal in which they occur, in that, they render it of inferior mechanical properties. Sulphur in steel is a well-known example of this. In the form of ferrous sulphide, because of the form in which it is distributed, that is, as thin films enveloping the grains, it renders the steel almost unworkable at a red heat. Fig. 9 shows the characteristic appearance of the sulphur in steel when in the form of ferrous sulphide and also when this has been converted into manganese sulphide after proper treatment. The inclusions of manganese sulphide are not particularly harmful in the metal, that is, no more so than any similar inclusions are.

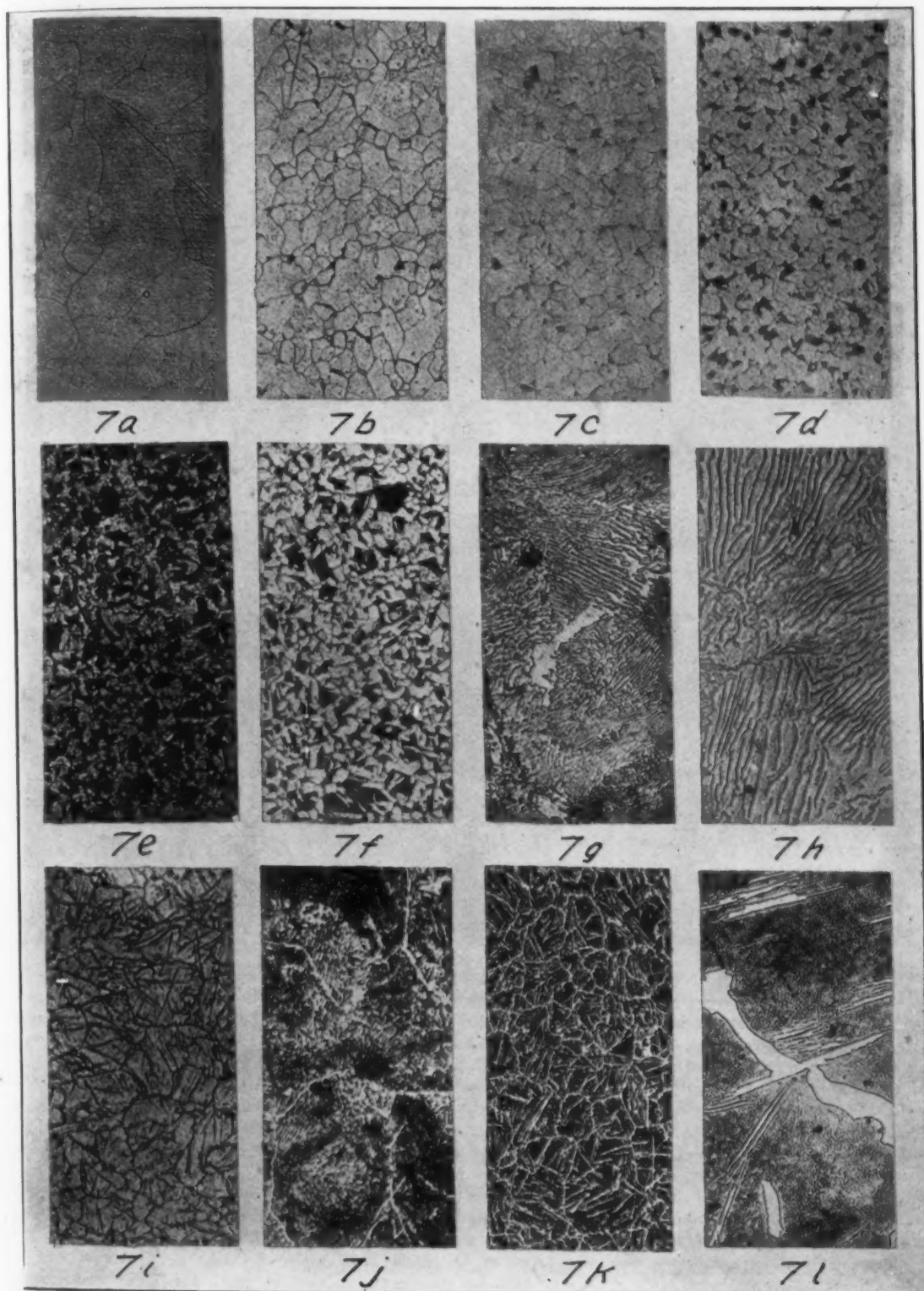
Temperature

The temperature to which a metal or alloy is heated, after it has been formed, has in most cases a marked influence upon its structure. These structural changes dependent upon heating may be conveniently classed as equilibrium changes, grain growth, and phase changes.

Practically all metals and alloys when cast, even upon slow cooling are far from being in a condition of structural equilibrium such as the phase rule predicates for the given conditions of composition and temperature. Metals, unless exceptionally pure and alloys normally show a cored or dendritic structure when in the cast state. This is a natural consequence of the selective process of freezing by which they solidify. In each crystal a branching or tree-like core which is relatively rich in the element of highest melting point is first formed and non-soluble impurities collect and constituents of lower melting point form in the interstices between the branches, the average composition of the material at such points being quite different from that of the core. When an alloy showing such a cored structure is heated for a time at a relatively high temperature the principal effect is to erase the structural pattern by allowing diffusion to take place within the body of each crystal so that chemical homogeneity is approached. Unless the material has been subjected to other conditions, such as straining by mechanical deformation or its equivalent, excessively rapid cooling from a very high temperature, as well as phase transformations, change of grain-size in a cast alloy does not take place upon heating. The principal effect



Figs. 6a-6h—Microstructure of the principal types of alloys of the copper-zinc series. $\times 100$.
 Fig. 6a—Alpha brass, annealed after cold work, etched with acidified aqueous solution of ferrite chloride. Fig. 6b—Alpha-Beta brass, hot-rolled, yellow matrix of beta containing reddish figures of alpha; etched with a dilute solution of sulphuric acid containing potassium dichromate. Fig. 6c—Beta brass, cast, golden yellow in color; etched with an ammoniacal solution of copper ammonium chloride. Fig. 6d—Gamma brass, cast, yellow matrix of beta containing silvery gray crystallites of gamma; etched with aqueous solution of ammonium persulphate. Fig. 6e—Gamma brass, cast; silvery gray in color, hard and brittle; etched as in Fig. 6d. Fig. 6f—Gamma-epsilon brass, cast; matrix of gamma containing the eutectoid of gamma and epsilon; etched as in Fig. 6d. Fig. 6g—Epsilon brass, cast, slightly purple when etched; etching reagent ammonium hydroxide and ammonium persulphate. Fig. 6h—Epsilon-eta brass, zinc-rich matrix of eta containing bright unetched crystallites of epsilon, etched as in Fig. 6d.



Figs. 7a-7l—Microstructure of typical annealed iron-carbon alloys (steels) illustrating the effect of variations in carbon content upon structure. Fig. 7a—Ferrite, electrolytic iron melted in vacuo. Figs. 7b-7g—Inclusive. Steels of ferrite-pearlite structure containing progressively increasing amounts of carbon as follows: Fig. 7b, 0.03 per cent. Fig. 7c, 0.07 per cent; Fig. 7d, 0.24 per cent; Fig. 7e, 0.32 per cent; Fig. 7f, 0.59 per cent; Fig. 7g, 0.68 per cent. Fig. 7h—Eutectoid steel, 0.85 per cent carbon. Fig. 7i-7l inclusive. Steels of pearlite-cementite structure containing progressively increasing amounts of carbon as follows: Fig. 7i, 1.14 per cent; Fig. 7j, 1.14 per cent; Fig. 7k, 1.45 per cent; Fig. 7l, 1.70 per cent. $\times 100$ except Figs. 7g, 7h and 7j, $\times 500$. Etching reagent; 2 per cent alcoholic solution of nitric acid except Fig. 7i for which boiling alkaline solution of sodium picrate was used.

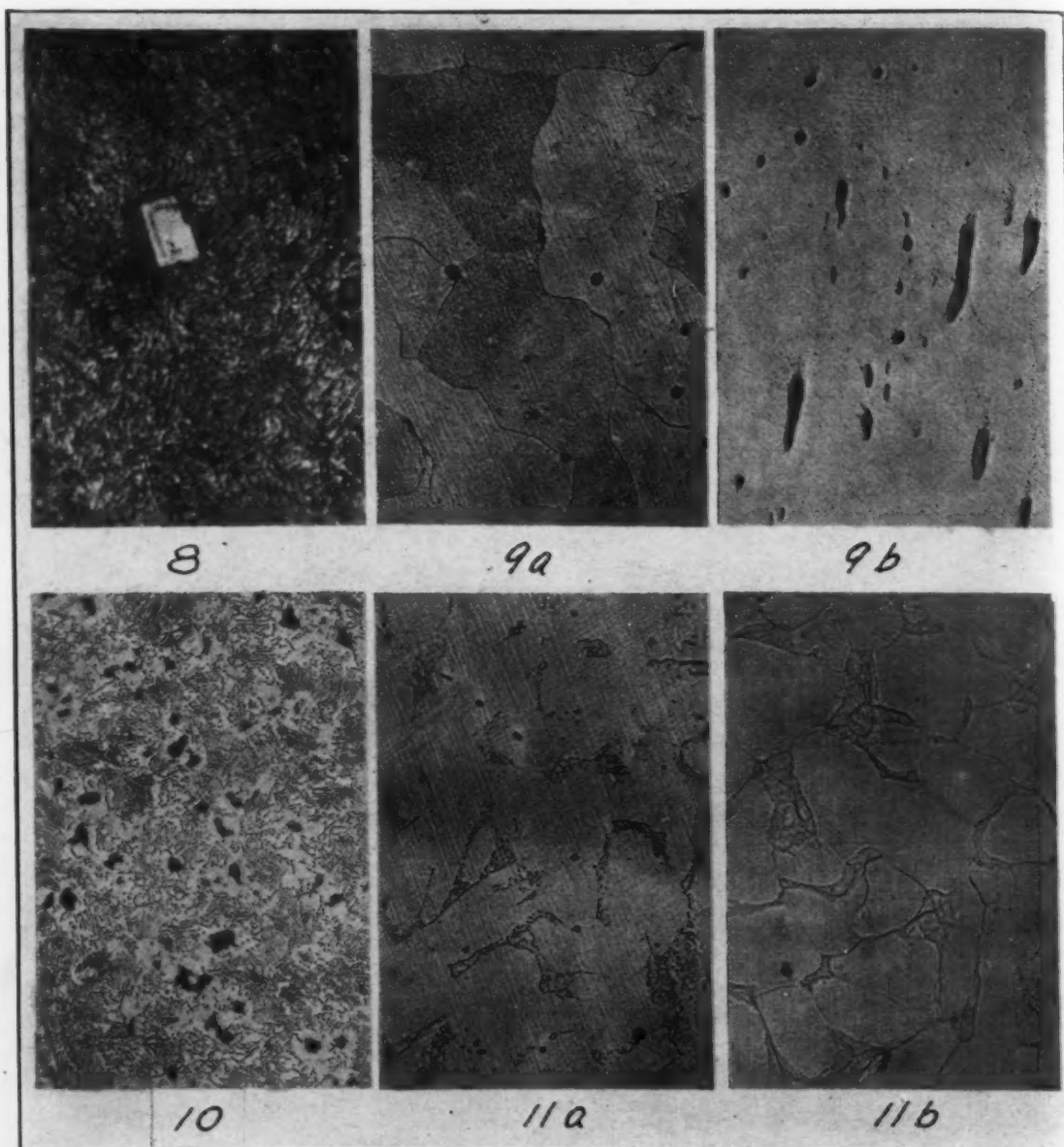


Fig. 8—Characteristic appearance of an inclusion caused by the addition of titanium to steel, $\times 1000$. Etching reagent, 2 per cent alcoholic solution of nitric acid. Figs. 9a-9b—Microstructure of low-carbon steel illustrating the forms in which sulphur may occur. Fig. 9a—Longitudinal section of the segregated center of a 2-inch round bar intended for chains. It was impossible to forge and weld the material satisfactorily on account of the films of ferrous sulphide enveloping the grains, $\times 100$. Etching reagent, 2 per cent alcoholic solution of nitric acid followed by hot alkaline sodium picrate. Fig. 9b—Longitudinal section of steel rod intended for use in an automatic lathe. The sulphur is in the form of isolated globules of manganese sulphide. $\times 100$. Fig. 10—Microstructure of high-carbon steel in which graphitization has occurred. This is a tool steel, 1 per cent carbon, showing specks of graphite which have formed at the expense of the combined carbon; each speck of graphite is surrounded by an area of ferrite, percentage of graphite, 0.51 per cent, $\times 100$. Etching medium, 2 per cent alcoholic solution of nitric acid. Figs. 11a-11b—Microstructure of 0.18 per cent carbon steel as it exists at ordinary temperatures and at relatively high temperatures (basis of heat treatment). Fig. 11a—Pearlite-ferrite structure of the material at ordinary temperatures, revealed by etching with 2 per cent alcoholic solution of nitric acid, $\times 100$. Fig. 11b—Same specimen as Fig. 11a, high-temperature structure revealed by heating the polished specimen in vacuo 30 minutes at 750 degrees Cent., above the A_1 transformation, and cooling in vacuo. A pronounced volume change, which is opposite in its character to that caused by heat alone, occurs in the steel during its transformation at the critical temperature. The deformation of the polished surface due to this change in volume, reveals the extent to which the austenitic solid solution resulting from the transformation of the pearlite merged with the ferrite, has progressed. $\times 100$.

of the heat upon the chemically unhomogeneous cast material is to render it more nearly uniform in its composition by permitting diffusion, and in some cases solution of certain constituents, to occur.

Another effect of heat is the decomposition of a compound, as is illustrated by the formation of graphite from cementite during the heating of white cast iron and in some cases in high-carbon steels. (Fig. 10).

Grain Growth

The most striking change occurring in the structure of metals and alloys upon heating is the increase in grain size which often occurs. Such a change in grain size, usually necessitates a preliminary straining of the material. Cast alloys, at least those which involve no phase change upon heating, will show no increase in grain size even after several months' heating unless the material has been strained in some way. Since so many metals and alloys are subjected to mechanical work of some kind in their fabrication or to other conditions in special cases which bring about grain growth upon subsequent heating, the fact is often lost sight of that grain growth is not the simple result of heating only, other conditions are necessary to bring it about.

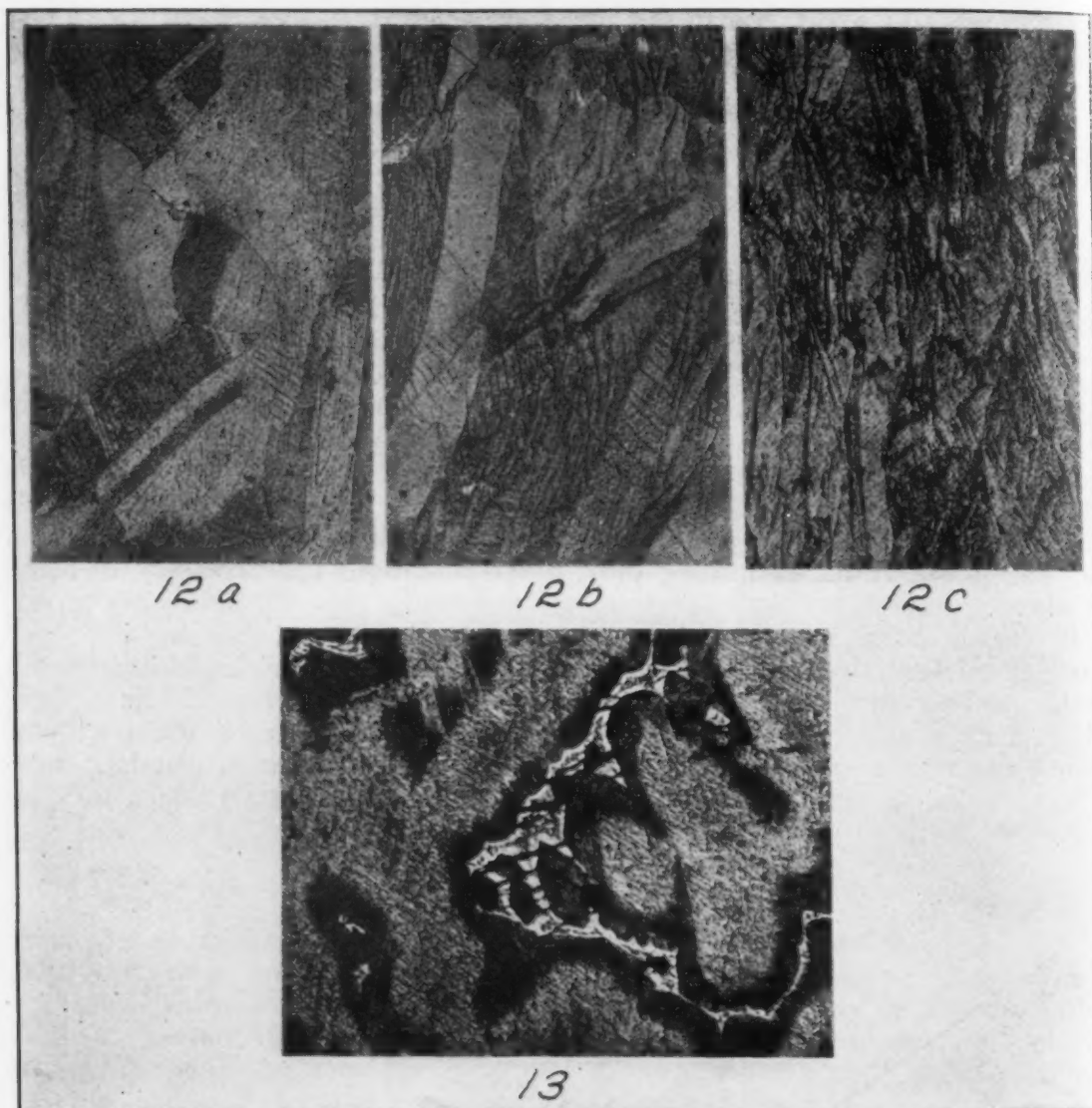
The increase in grain size which results in a steel bar by improper annealing is only too familiar. The distortion of the material which occurred in the rolling of the metal as well as the fact that the material is subject to a phase change upon heating accounts for the pronounced grain growth which occurred upon heating. A coarsely-grained condition in metals is usually regarded as very undesirable and particularly so in metals which may be subjected to shock or similar conditions in service.

Phase Changes

In a great many alloys, pronounced structural changes occur upon heating to certain definite temperatures which of course vary with the different alloys under consideration. Such changes are to be ascribed to phase changes or transformations within the material. By quickly cooling an alloy which exhibits such changes, from a temperature somewhat higher than that at which the transformation occurs, the structure normally existing only at the higher temperature persists to a large extent, in the material at room temperature, the alloy being in a state of unstable equilibrium.

This fact is of very great industrial importance, the art of heat treatment of alloys, particularly steel, for high mechanical properties depends upon this fact. Fig. 11 shows the structure of a low carbon steel as usually observed and the structure of the same as it exists at a temperature somewhat above the first or A_1 transformation, as recorded by a special method of heat-etching by heating the polished specimen in vacuo. The definite boundary separating the austenite resulting from the transformation of the pearlite from the ferrite matrix may be plainly seen.

Phase changes or transformations in alloys are accompanied by energy (heat) manifestations. Hence it is much easier to investigate and establish the temperature at which the changes occur by the relatively simple means of THERMAL ANALYSIS rather than by the tedious and complicated methods necessary for the determination of the high-temperature structure of the material. Thermal analysis may be regarded then as the convenient means for demonstrating the structural changes which occur in alloys upon heating as well as the energy changes which accompany them. It may be noted, however, that some energy changes have been observed for which any pos-



Figs. 12a-12c—Microstructure of brass illustrating progressive stages in the crystalline distortion produced by cold-working. $\times 100$. Figs. 12a, 12b and 12c show three stages in the crystalline distortion of cartridge brass (approximate composition, copper 70 per cent, zinc 30 per cent) by cold-working the alloy. The series of parallel lines within any one crystal represents the planes along which the metal slips. They are of the nature of "slip bands" but persist after etching. Etching reagent, ammoniacal solution of copper ammonium chloride. Fig. 13—Microstructure of cast zinc-bronze which has been stressed in tension. $\times 250$. The stress was applied at right angles to the cracks which formed in the hard brittle constituent of the alloy; approximate composition of alloy, copper 68 per cent; tin, 10 per cent; zinc, 2 per cent. Etching reagent, concentrated ammonium hydroxide.

sible accompanying structural change is so minute as to be beyond the range of the methods now used for observing the structure of metals.

Working of Metals

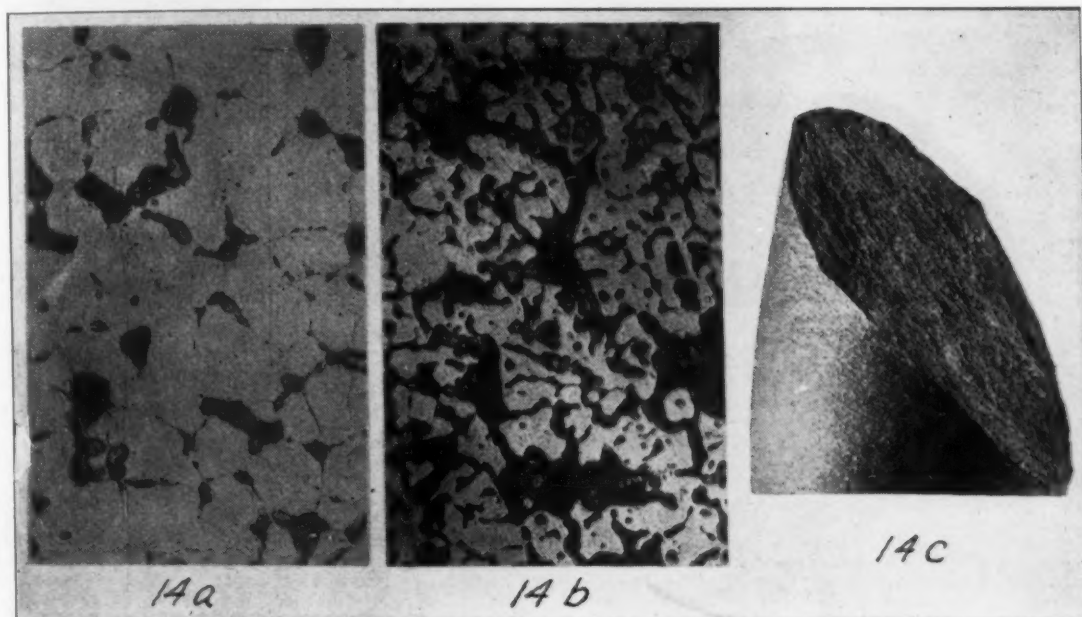
One of the most potent factors affecting the structure of metals and alloys is the amount of mechanical working received during fabrication after casting. Aside from the part played by the straining of metals in causing recrystallization and grain growth upon subsequent heating as explained above, the structure of the metal is often profoundly changed by the deformation of the material. Thus sections of a metal parallel to the direction of working will differ very materially in their appearance from those perpen-

dicular to the same. Fig. 12 illustrates how the deformation or change of crystal form is brought about in cartridge brass by means of an internal slip or FAULTING within the individual crystals along definite planes. These FAULTS persist in the crystals and are revealed when the metal is etched, and are not to be regarded necessarily as discontinuities within the crystals.

The depth to which a cast metal has been distorted by cold working, for example, in machining operations, can often be detected by making use of the fact that upon heating, recrystallization of the cold-worked metal will occur.

Effects of Structure Upon Properties

The ultimate aim of any metallographic examination is to show in what manner and to what extent the characteristics of the material, particularly

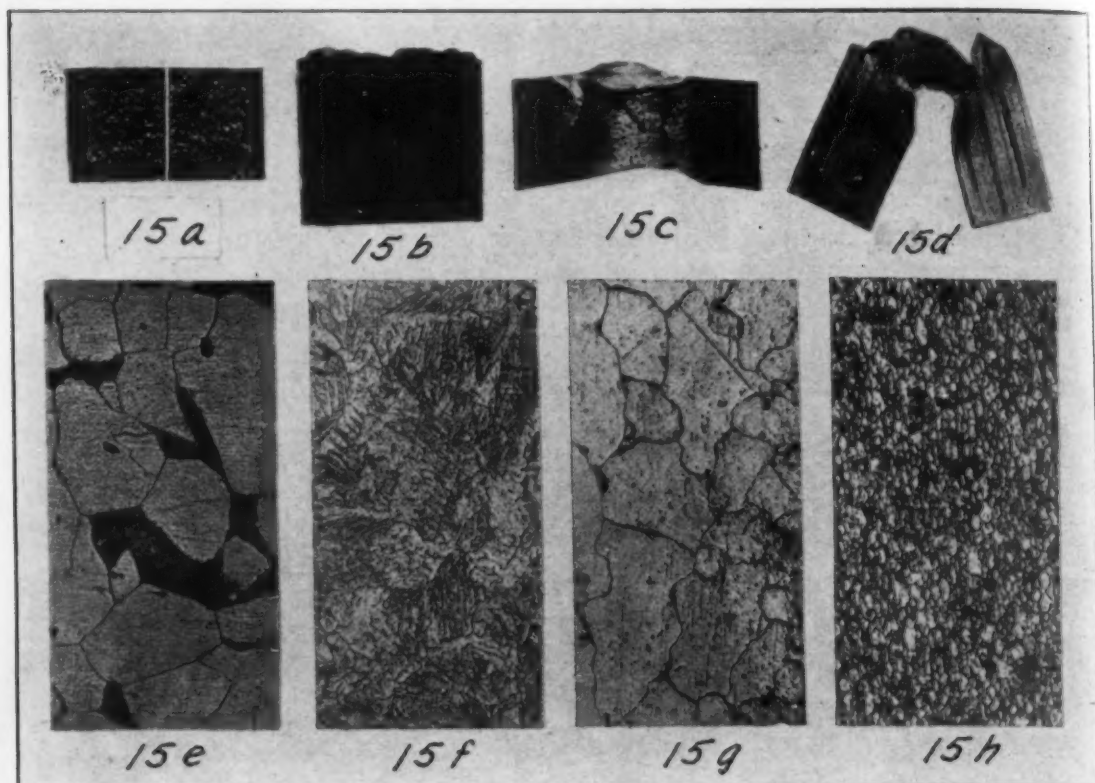


Figs. 14a-14c—Microstructure of copper-lead alloys and appearance of specimens of the same after testing in compression. Fig. 14a—Alloy of approximate composition; copper, 77 per cent; lead, 23 per cent. $\times 100$. Fig. 14b—Alloy of approximate composition; copper, 60 per cent; lead, 40 per cent. $\times 100$. The black network indicates the spaces in the copper "sponge" initially filled with globules of lead, traces of which still remain in place after the polishing of the sample. The specimens were slightly etched with concentrated nitric acid. Fig. 14c—Compression specimen of alloy Fig 14b, after-test. $\times 1$. The specimen sheared when compressed sufficiently, in a manner similar to "brittle" alloys.

the mechanical properties, are dependent upon the particular features characterizing the structure of the metal under observation. To discuss this phase of the subject, in this paper, even in a manner only approximately complete, is manifestly impossible. Only a few of the most obvious effects of structure upon the properties will be mentioned.

Hard and Soft Constituents

Many of the alloys most useful from the industrial standpoint, consist of two or more constituents which vary very widely in their characteristics. One is often relatively soft and ductile, while a second is hard and brittle. Such a condition occurs in steels, in aluminum casting alloys, and in bronzes, particularly those for bearing purposes. The softer constituents gives the required ductility, while stiffness and strength are contributed by the harder one which is disseminated throughout the soft matrix.



Figs. 15a-15h—Appearance of specimens of low-carbon steel with different thermal treatments showing the relation of impact properties to the microstructure of the material. Figs. 15a-15b—Fractured face and side-view of specimen of low-carbon steel broken by the Fremont impact test of a falling weight. $\times 1\frac{1}{2}$. Figs. 15c-15d—Fractured face, and side view of a second specimen of the same material tested in the same way. $\times 1\frac{1}{2}$. Fig. 15e—Microstructure of specimen of Figs. 15a-15b, $\times 100$. The steel has been rendered coarsely-grained evidently by overheating in the annealing process. Fig. 15f—Microstructure of specimen Figs. 15c-15d. $\times 100$. Etching reagent, 2 per cent alcoholic solution of nitric acid. Fig. 15g—Microstructure of soft iron wire (very low carbon steel) which was as "brittle as glass" when an attempt was made to bend it at the temperature of liquid air. $\times 100$. Fig. 15h—Microstructure of a wire of similar composition which proved to be very tough at the temperature of liquid air and withstood several complete bends, 180 degrees, before breaking. $\times 100$. Note the difference in grain size of the brittle material, Fig. 15e and Fig. 15g, as compared with similar metal in the tough condition, Fig. 15f and Fig. 15h.

Fig. 13 shows a specimen of cast zinc-bronze which was stressed in tension until fracture occurred. The soft ductile copper-rich matrix easily adapted itself to the applied loading, the hard brittle tin-rich constituent was shattered and broken, as shown, when stressed sufficiently. The examination of a test specimen of an aluminum casting alloy broken in tension often is very enlightening concerning the results of the test. The hard constituent of the alloy consisting of a compound of aluminum and copper (Cu Al_2), is often sufficient in amount to form a continuous network throughout the alloy. The course or path of the fracture of the test specimen is determined by this network, thus the results of a tension test of such a material depend primarily upon the amount and the properties of this constituent.

Soft Ductile Constituents

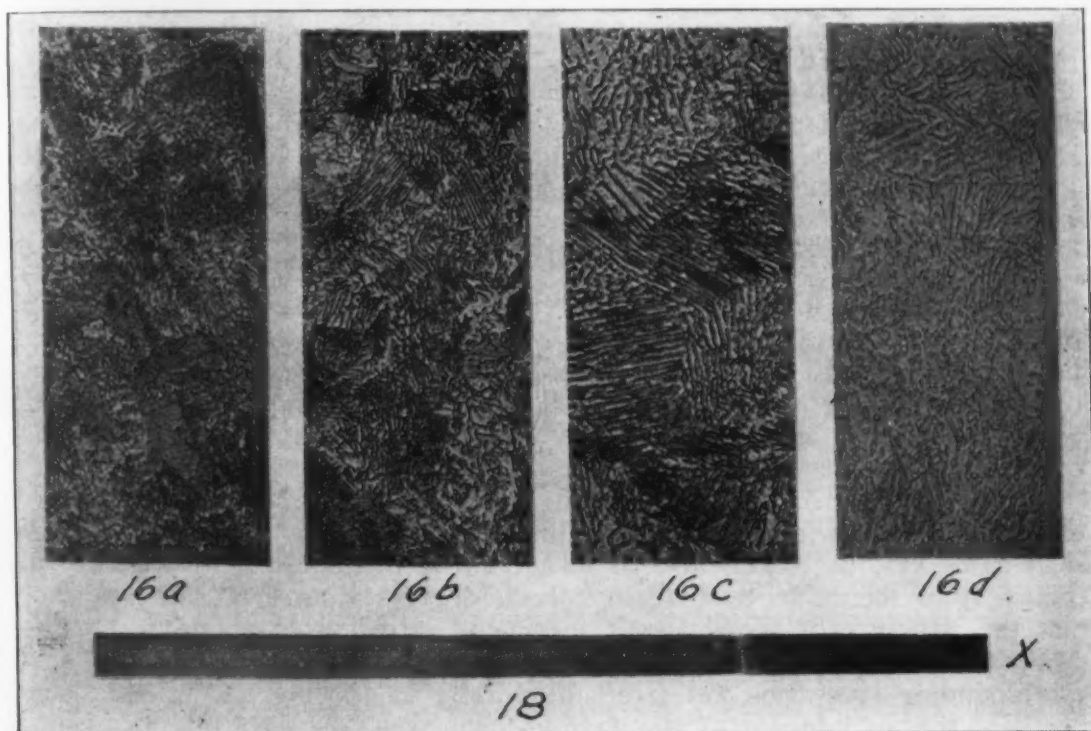
Copper and lead do not alloy with each other in the sense that most metals do. The ALLOY of these metals may be considered, for convenience, as a copper sponge, the interstices of which are filled with globules of lead, as is shown in Fig. 14.

Although both copper and lead, when reasonably pure, are highly ductile, the mixture of the two behaves in a rather anomalous manner when tested.

The behavior of the material when stressed in tension is somewhat as might be expected. It is somewhat ductile but is decidedly inferior to metallic copper in its properties. The continuity of the copper matrix is so broken up and weakened by the enclosed globules of lead that the resulting tensile properties are correspondingly lowered. Although each of the two constituents is decidedly ductile under compression, the mixture of the two behaves in a manner characteristic of a brittle material. Instead of flattening to any appreciable extent the specimen shears in a manner such as is expected, for example, in cast iron. The enclosed globules of the lead undoubtedly contribute largely to the failure of the specimen in the manner shown by their action as a LUBRICANT. The ultimate strength in compression of lead is very much lower than that of copper, thus the lead yields under the applied loading and FLOWS long before the copper is stressed to a degree which would cause appreciable deformation.

Orientation of Test Specimen With Respect of Material Tested

A worked metal has a more or less FIBROUS structure depending largely upon variations in composition across a section of the ingot used and particularly upon the various inclusions within the metal. It is evident that the mechanical properties, when measured ACROSS a laminated or fibrous material will be quite different from those of the same material, the test specimen of which was cut PARALLEL to the course of the fibres. In the latter



Figs. 16a-16d—Microstructure of eutectoid carbon steel (0.85 per cent carbon) showing the effect of rate of cooling upon the physical state of the pearlite. $\times 500$. The specimens were heated to 800 degrees Cent. and cooled as follows: Fig. 16a, cooled in air; the material consists largely of sorbite. Fig. 16b, cooled in lime; the material contains patches of fine lamellar pearlite and some sorbite. Fig. 16c, cooled in furnace; coarse lamellar pearlite with some spheroidizing of the pearlite has resulted. Fig. 16d, cooled in furnace at a much slower rate than in Fig. 16c, the pearlite has been largely spheroidized or "divorced." Etching reagent, 5 per cent alcoholic solution of picric acid. Fig. 18—Appearance of a 1 per cent steel rod hardened, differentially tempered, and then immersed in dilute sulphuric acid. $\times 1$. The hardened rod was differentially tempered by heating the end x, the other one being kept cold by water.

case which covers by far the greater majority of the test specimens used in industrial testing, the mechanical properties are not seriously affected. A striking illustration of the effect of the orientation of the test specimen to mechanical properties is shown in Table I.

Table I
Tensile Properties of "Flaky Steel" as Revealed by Transverse and by Longitudinal Test Specimens.

Specimen No.	Proportional limit lb. sq. in.	Yield Point lb. sq. in.	Ultimate Strength lb. sq. in.	Reduction of area per cent	Elongation in 2 in. pc.	Modulus of Elasticity lb. sq. in.
T	53,500	56,100	59,200	1.5	1.5	29,000,000
Tl	65,000	67,000	92,950	5.0	3.5	29,000,000
L	62,500	65,000	106,500	52.0	26.5	29,500,000
Ll	62,500	65,000	106,850	50.5	26.0	29,300,000

When such material is subjected to some of the dynamic methods of testing, impact, fatigue, etc., the difference in the results obtained for the transverse specimen as compared with those for the longitudinal specimen, is usually even more marked than those of the tension test.

Coarsely Grained Metals

Coarsely grained metals are quite universally regarded with disfavor although there often appears to be no evidence at hand to demonstrate the unsuitability of such material for many purposes. The brittleness, usually attributed to large grain size is not very well revealed by a tension test, at least as ordinarily carried out. A shock or impact test reveals the effect of coarse grain upon mechanical properties in a much more striking manner, (Fig. 15).

Physical State of Microscopic Constituents

Considerable investigative work has been done to show how the mechanical properties of carbon steels, particularly those of eutectoid composition, vary with the physical state of the pearlite, the steel being in the softened state throughout and the pearlite ranging from the lamellar type through various stages to the completely DIVORCED or SPHEROIDIZED condition.

The influence of the physical state of the pearlite in steel upon the properties is well shown by a study of the magnetic characteristics of the same steel after various treatments. The specimens of the steel of Fig. 16 were cooled from the same temperature (800 degrees Cent.) at rates so chosen that the structure of the different specimens varied from a fine sorbitic condition to a divorced or spheroidized pearlite. The magnetic properties of the corresponding specimens are given graphically in Fig. 17. Without discussing here the significance of the various properties revealed by the magnetic tests it will be evident that the properties of the steel are affected to a marked degree by the changes which have been brought about in the physical state of the pearlite. Corresponding differences in the mechanical properties also would be found upon testing although perhaps of not so great a magnitude as in the magnetic properties since the magnetic tests are much more sensitive than the ordinary mechanical ones and often reveal changes which are detectable by almost no other means.

Chemical Properties

The chemical property of metals and alloys which is probably most important industrially, is that designated by the rather loose term of *solubility*. Upon this property depends the etching of metallographic specimens, the coloring of metallic surfaces, the corrodibility of materials under service conditions, and often, by the selective corrosion of certain constituents, the complete deterioration of the entire alloy in service. This property of an alloy is often influenced to a marked degree by the structure and the following examples are cited as typical of this effect of structure upon properties.

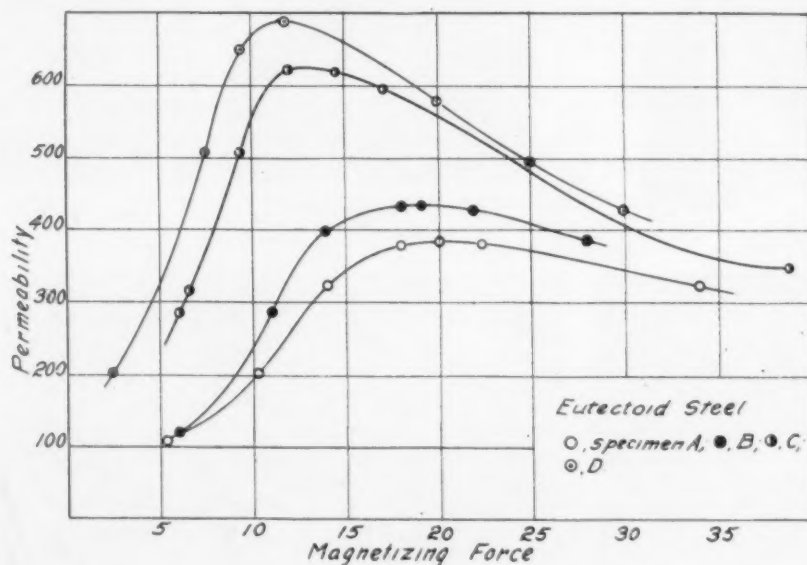


Fig. 17—Magnetic properties (permeability $\frac{B}{H}$ versus magnetizing force H) of eutectoid carbon steel after different annealing treatments.

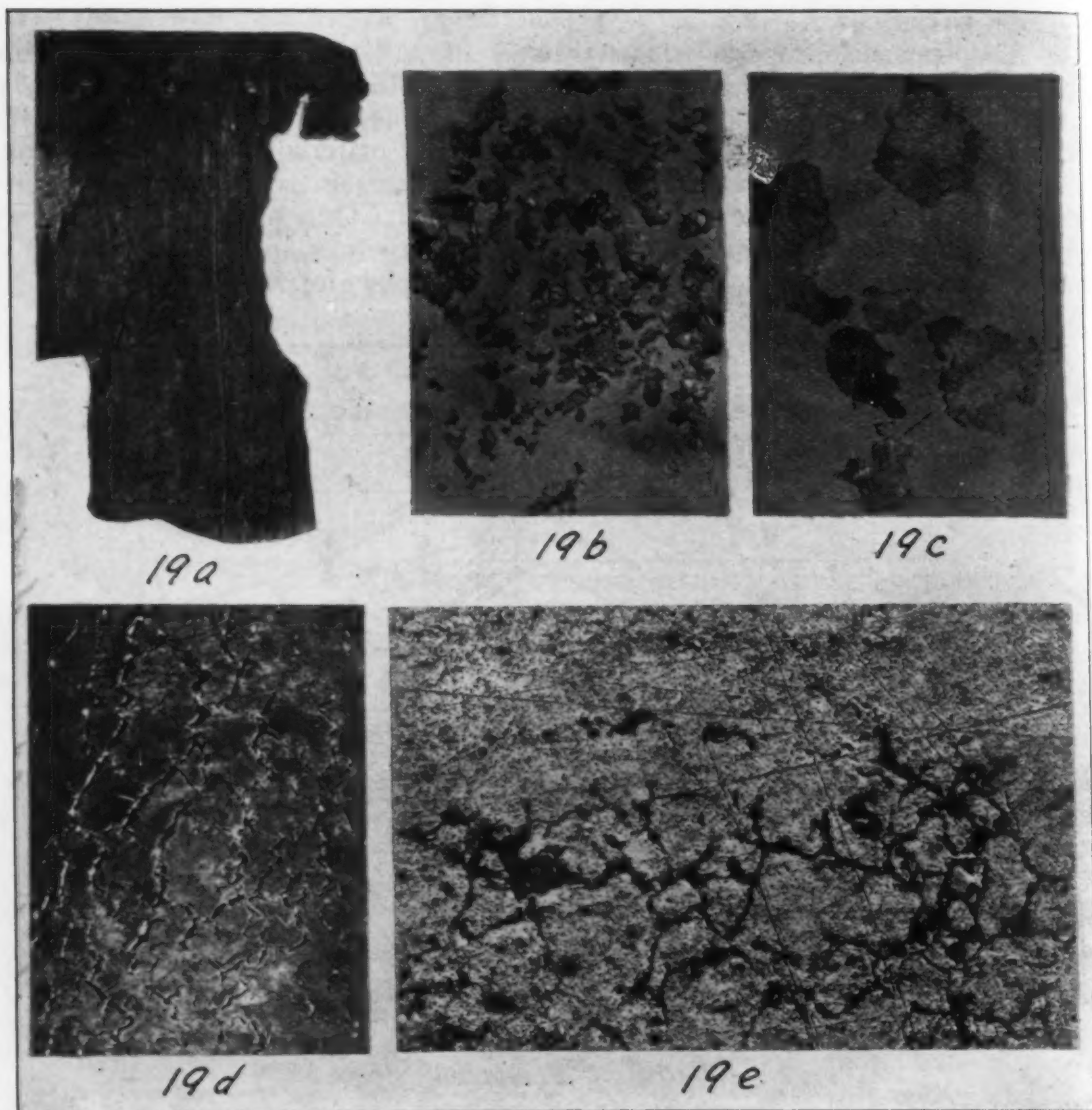
Solubility of Tempered Steels

It is quite well recognized that the solubility of steel varies considerably according to the heat treatment which it has received. To illustrate this, a rod of high carbon steel (approximately 1 per cent carbon) was hardened by quenching in water from a temperature of 765 degrees Cent. The hardened rod was differently tempered by heating one end to approximately 850 degrees Cent. while the other was kept cool with water. Thus the rod represented at different points along its length, tempering to all temperatures between the two extremes. When immersed in dilute sulphuric acid (20 per cent solution) for 17 hours the appearance shown in Fig. 18 was produced. The material in one of the intermediate stages of tempering is the most readily soluble, rather than the very hard or the very soft portions.

Considerable attention has been given to this property of tempered steels by foreign metallurgists and it has been shown, that the rate of solubility can be used as an index of the tempering a specimen of steel has received. Maximum solubility corresponds to a tempering at 400 degrees Cent. A special name, Osmondite, has been given to steel in this particular condition on account of its characteristic properties.

Corrosion

Only a brief mention will be made here of how structural features aid



Figs. 19a-19e—Appearance of lead after accelerated corrosion and of commercial lead which corroded in service. Fig. 19d—Surface appearance of a sheet of high grade lead (99.99 per cent) after immersion of 24 days in a solution of lead acetate (N) and nitric acid (0.08N) and bent at a slight angle. An intercrystalline brittleness resulted from the corrosive attack. $\times 5$. Fig. 19b—Crystals which were detached from a sheet of commercial lead (lead, 99.72 per cent; antimony, 0.07 per cent; iron, 0.02 per cent; tin, 0.14 per cent) immersed for four days in an acidified solution of lead acetate. (400 grams lead acetate, 100 cubic centimeters nitric acid, 1000 cubic centimeters water). $\times 8$. The corrosion of the lead was intercrystalline in nature. Fig. 19c—Some of the crystals of Fig. 19b flattened out, $\times 8$. Each crystal retained the characteristic malleability of lead, although the sheet as a whole was brittle. Fig. 19a—Appearance of a lead cable sheathing which corroded in service, approximate composition, tin 1.09 per cent, lead 98.3 per cent. $\times 1\frac{1}{2}$. Fig. 19e—Cross-section of specimen Fig. 19a unetched. The lower edge of the micrograph coincided with the outer surface of the sheath. The corrosive attack of the metal was intercrystalline in its nature. $\times 50$.

in the process of corrosion. In general the corrosive attack on a metal is more pronounced in the direction of the fibers than across them. This is most marked in case of accelerated corrosion by exposure to sea air, sea water or similar conditions. This may be attributed largely to the mechanical effect of inclusion streaks which afford lodgement for moisture so that the attack at such points is accelerated and to the difference in the electrochemical properties of streaks of the metal in various stages of cold-working. Brass containing approximately 60 per cent copper and 40 per cent zinc often used near

sea water or similar exposures exemplifies well the specific effect of a metallographic constituent upon the corrosion of a metallic material. Such a brass has a duplex structure; one constituent, the α being much richer in copper than is the second or β . The difference in the electrochemical potential of the two, α and β contribute to bring about difference in the resistance of the two to the action of sea water. The zinc from the β is leached out and a spongy mass of copper remains filling the spaces previously occupied by the β . Thus a weak brittle mass consisting of a sponge-like skeleton of the more or less unattacked α constituent and the pulverulent material resulting from the disintegration of the β , results.

A soft ductile metal like lead may under some conditions of accelerated corrosion become so brittle that it can be crumbled to powder in the fingers. This is most apt to occur if the lead is somewhat impure. Fig. 19 shows a section of a lead cable sheath which by electrolytic corrosion became so brittle that it could be reduced to a granular powder. Each grain, however, retained its initial ductility and the other characteristic properties of lead. The corrosive attack of the metal was essentially intercrystalline in character which was due largely in all probability to the impurity contained by the metal (1.09 per cent tin).

Applications of the Microscopy of Metals

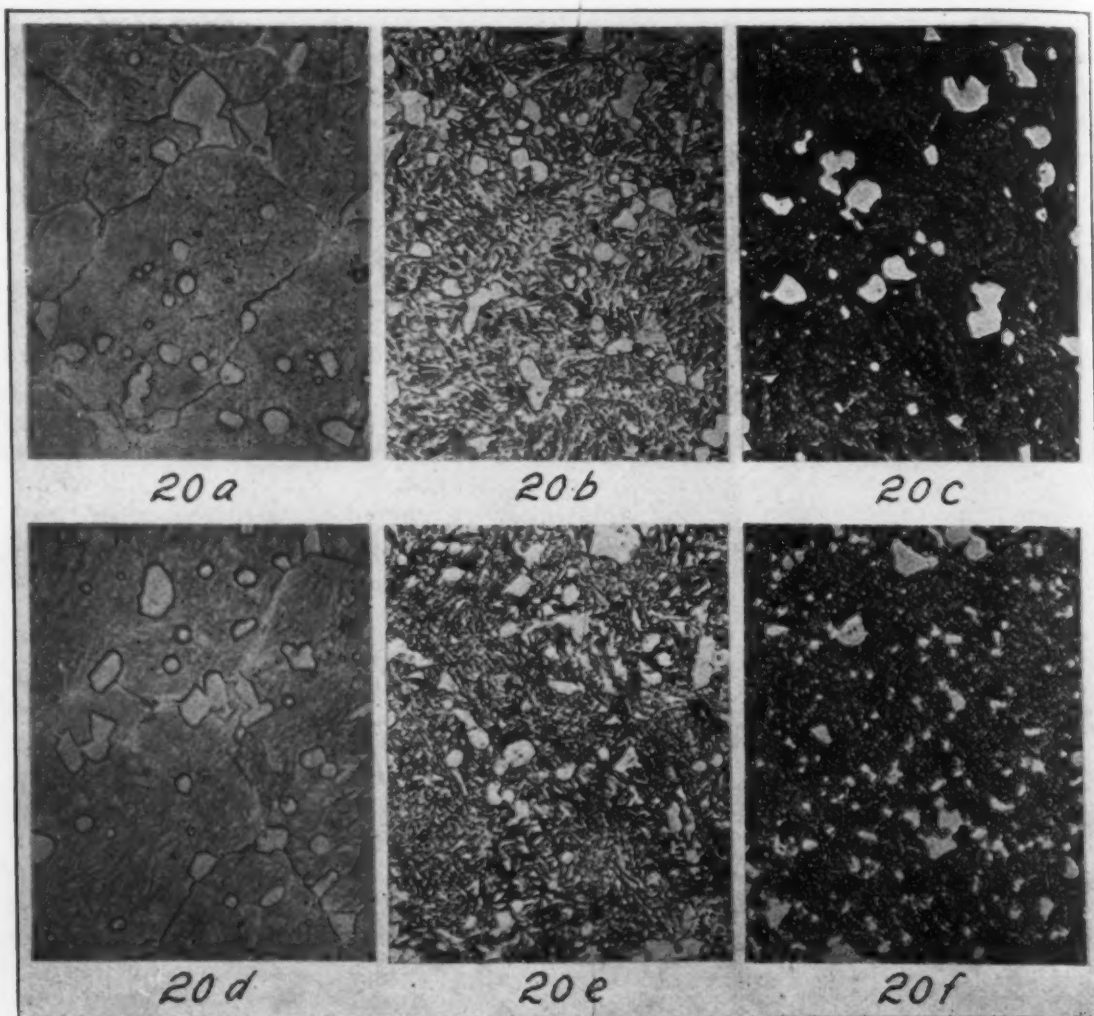
The most important industrial application of the microscopy of metals is undoubtedly its use in connection with the heat treatment of steels. Not only is it used for the routine method of examination of heat-treated stock to make certain that the prescribed treatment has been carried out and to show wherein lies the fault when the material after treatment does not show the expected mechanical properties but it is of inestimable service in specifying a proper heat treatment for new types of steels. A second important application of the method is to supplement chemical analysis. The description of the various applications can best be given by means of short references to a few typical cases rather than by a longer and more general discussion. Obviously, the discussion must be more or less fragmentary in character.

Relation of Microscopy to Heat Treatment

The question of grain size, grain refinement, etc. has already been referred to.

A knowledge of the microstructure is very helpful in explaining the peculiar characteristic properties of high-speed tool steels (Fig. 20) in order to specify properly the necessary heat treatment. When quenched from a sufficiently high temperature the material is, at least partially, austenitic in structure. Upon tempering at a relatively low temperature, it is converted into the martensitic state with an accompanying gain in hardness, usually termed *secondary* hardness. The martensitic state is changed into the troostitic condition only very slowly so that the material passes no further than the troostitic state upon tempering at a relatively high temperature. Hence this state together with the accompanying cutting properties (toughness and hardness) is retained by the material at the high temperature which prevails in the use of such tools.

Fig. 21 shows the structures which may be obtained by hardening a hypoeutectoid steel (carbon 0.46 per cent) by quenching from different temperatures. When a temperature only slightly above the transformation is used, considerable ferrite exists intermixed with the martensite and the material

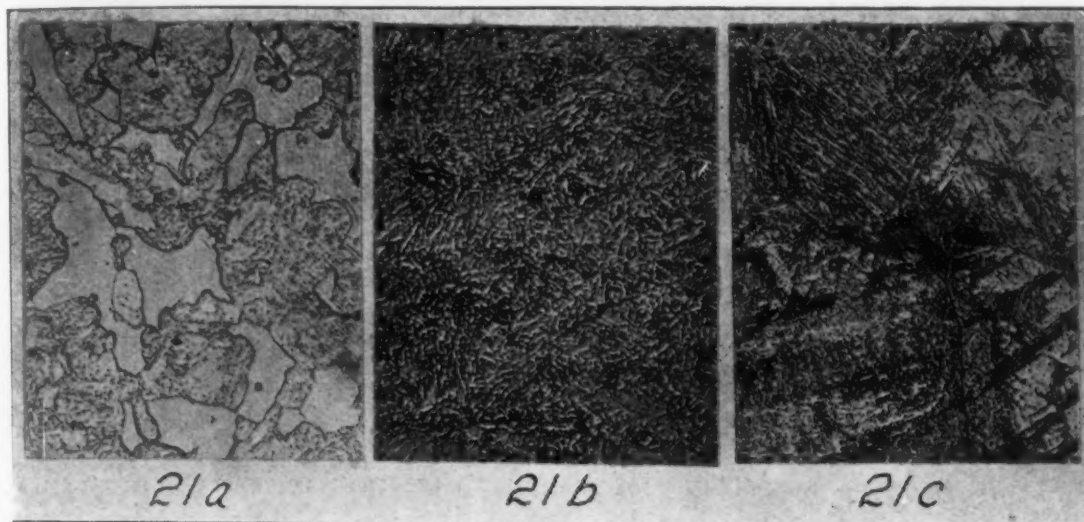


Figs. 20a-20f—Microstructure of high-speed tool steel illustrating the effect upon structure of tempering the hardened steel at different temperatures. $\times 500$. The micrographs show the structure of a steel containing 0.77 per cent carbon; 17.8 per cent tungsten; 3.5 per cent chromium; 0.74 per cent vanadium after the treatments given below:—Fig. 20a—Quenched in oil from 1290 degrees Cent. A polyhedral structure resulted from this treatment and the material was rendered largely austenitic in its properties. Fig. 20d—Specimen Fig. 20 a, tempered 30 minutes at 200 degrees Cent. The crystals show interior markings suggestive of the beginning of the change into the martensitic condition. Fig. 20b—Specimen Fig. 20 d, tempered 30 minutes at 400 degrees Cent., the martensitic pattern has been fully developed. Fig. 20e—Specimen Fig. 20b, tempered 30 minutes at 600 degrees Cent.; although in the troostitic state, the martensitic pattern is still evident. Fig. 20c—Specimen Fig. 20e, tempered 30 minutes at 700 degrees Cent. Tiny globules of carbide precipitated from the previously existing solid solution by the process of tempering have begun to appear. Fig. 20f—Specimen Fig. 20c, tempered 30 minutes at 800 degrees Cent. The particles of carbide are more plainly visible than in Fig. 20c and the material is approaching the annealed state. Etching reagent, 2 per cent alcoholic nitric acid.

has not been fully hardened. Statements from as noted a source as the International Association for Testing Materials suggest that sorbite should be obtained by such a treatment. When quenched from above the A_{2-3} transformation temperature, no ferrite remains and a fine martensitic structure results. If a still higher temperature is used the martensitic structure becomes very coarse and intercrystalline cracks often form upon quenching.

Undesirable properties of steel are sometimes attributed to faulty heat-treatment used for the material, a microscopic examination of which shows that the cause is an entirely different one. A section of a forging of nickel steel intended for rifle parts was submitted for examination. Difficulties

had been encountered in drilling and the attempt had been made to overcome these by various annealings of the material. The microscopic examination of the annealed piece revealed a martensitic core while the outer portions were of the usual ferrite-pearlite structure (Fig. 22). Subsequent chemical analysis showed that the nickel content of the central portion was very much higher than that of the outer parts, enough so as to render the material martensitic even upon slow cooling. Evidently heat treatment could not be expected to



Figs. 21a-21c—Microstructure of medium carbon steel after different hardening treatments. Fig. 21a—Specimen of 0.46 per cent carbon steel quenched in water after heating 15 minutes at 750 degrees Cent. (1380 degrees Fahr.), just above the A_1 transformation. The structure consists of ferrite and martensite, $\times 500$. Fig. 21b—Specimen similar to Fig. 21a, quenched in water after heating 15 minutes at 850 degrees Cent. (1515 degrees Fahr.), just above the A_2 transformation. The structure consists entirely of very fine martensite, $\times 500$. Fig. 21c—Specimen similar to Fig. 21a, quenched in water after heating 15 minutes at 1200 degrees Cent. (2190 degrees Fahr.). A very coarsely-grained martensitic structure has resulted in which intercrystalline quenching cracks are abundant. $\times 100$. Etching reagent, a 2 per cent alcoholic solution of nitric acid.

improve the machining properties of such material, the remedy had to be sought in the melting practice used in the production of the steel.

An interesting example of the effect of furnace atmosphere is the defect which may result in copper which has been improperly annealed. The metal may be rendered brittle and useless by numerous fine intercrystalline cracks throughout the interior. This is to be attributed to the action of the atmosphere in which it was heated rather than to the temperature used. The particles of cuprous oxide, which are always present to some extent in remelted copper, are reduced by hydrogen or other reducing gases which readily penetrate the heated metal. The pressure of the gaseous products resulting from their action upon the oxide is sufficient to produce the internal cracks throughout the hot metal.

Supplement to Chemical Analysis

The advantage which may be taken of a macroscopic examination in the proper sampling of a segregated steel for chemical analysis has already been referred to. Such an examination is also particularly valuable for some of the white metal alloys which are subject to *liquidation* during solidification on account of the difference in density of the various constituents, as is illustrated by lead-antimony alloys.

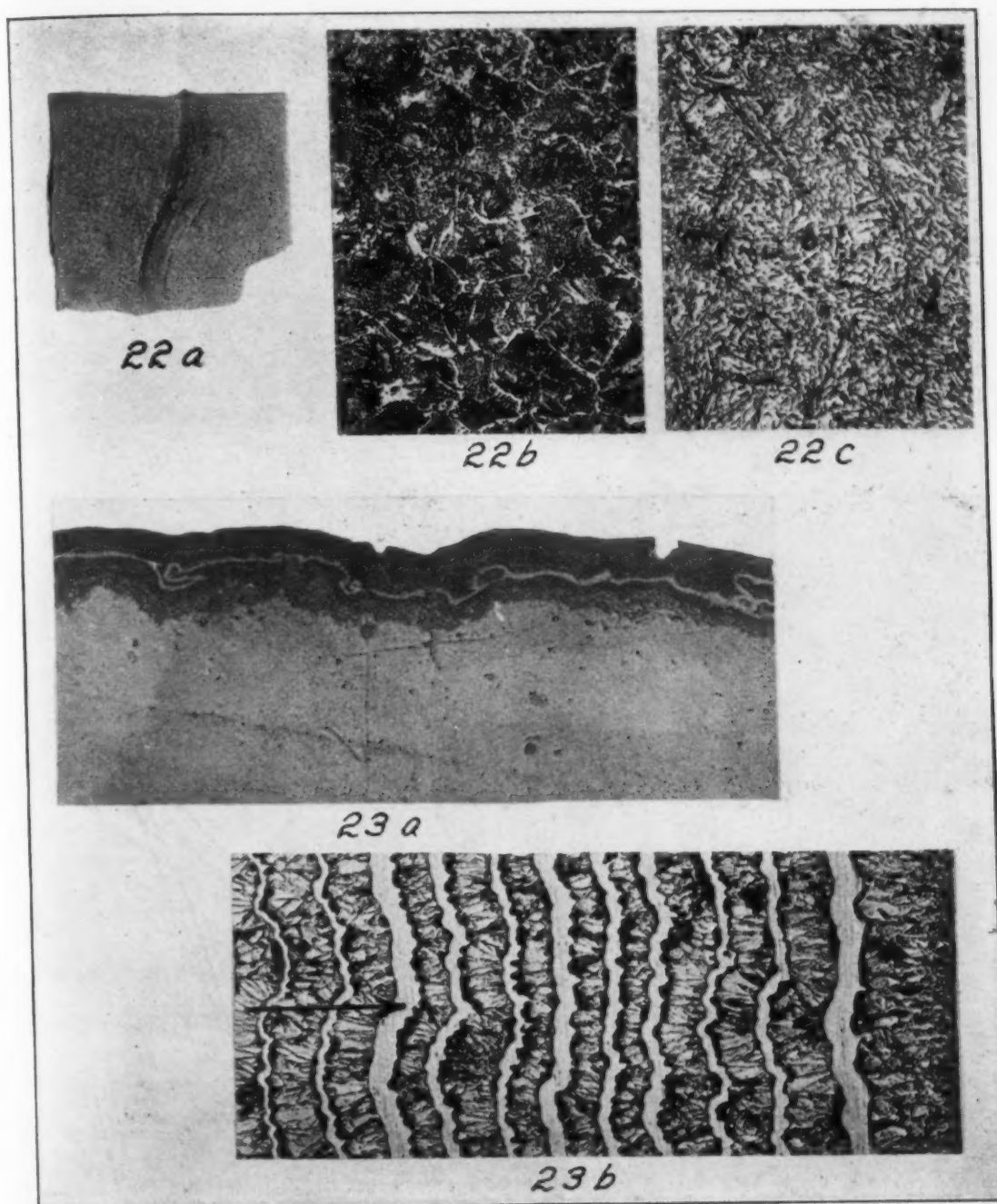
The microscopic method is of decided value in supplementing the chemical study of the various metallic coatings used for protective purposes particularly on iron and steels. The brass coating shown in Fig. 23 in reality consists of three layers, one of nickel and two of brass. It is evident that with this information in mind, the chemical determination of this coating can be carried out and interpreted in a much more logical way than without it. The duplex structure of electrolytic deposit of alternate layers of copper and nickel now being used with success to replace steel plates in engraving work is shown also in Fig. 23. The microscopic method may be used also in determining the thickness and distribution of the coating material. Although laborious, this method is often the only one available for such determinations.

Because of the relatively higher price for wrought iron as compared to mild steel there is at times a tendency to *adulterate* this product with additions of the cheaper metal. While the chemical analysis will indicate in a general way that such additions have been made, the metallographic method is almost indispensable for quickly revealing the extent of such contaminations. Fig. 24 shows the appearance of a specimen of commercial wrought iron which has been suitably prepared to show the results produced by the addition of low carbon steel to material of this kind.

Considerable importance is attached to the study of the occurrence of gases in metals, and in particular those gases which are given off by steel when heated in vacuo. Among the principal gases obtained in this manner is carbon monoxide. A study of the microstructure of specimens of steel after being heated in vacuo shows that a very appreciable decarburization occurs in such material, a fact which throws considerable light on the origin of at least some of the evolved gases. The carbon is often removed for a considerable depth at the surface of a specimen by heating in vacuo, and evidently a chemical reaction, the reverse of that by which carburization of steel in the cementation or case hardening process is brought about, occurs during the heating, giving rise to carbon monoxide as one of the products.

The chemical determination of slag in steel is at its best rather unsatisfactory. Even if good checks are obtained in duplicate determination, the interpretation of the results is a matter of considerable difficulty. That this must be so is evident upon an examination of the microstructure of a slag thread from wrought iron. The duplex nature of this simple slag may be plainly shown and it may be inferred that in the case of the complex steels, in the manufacture of which the additions to the metal are often several in number and varied in composition, the resulting slag must be correspondingly complex in its nature.

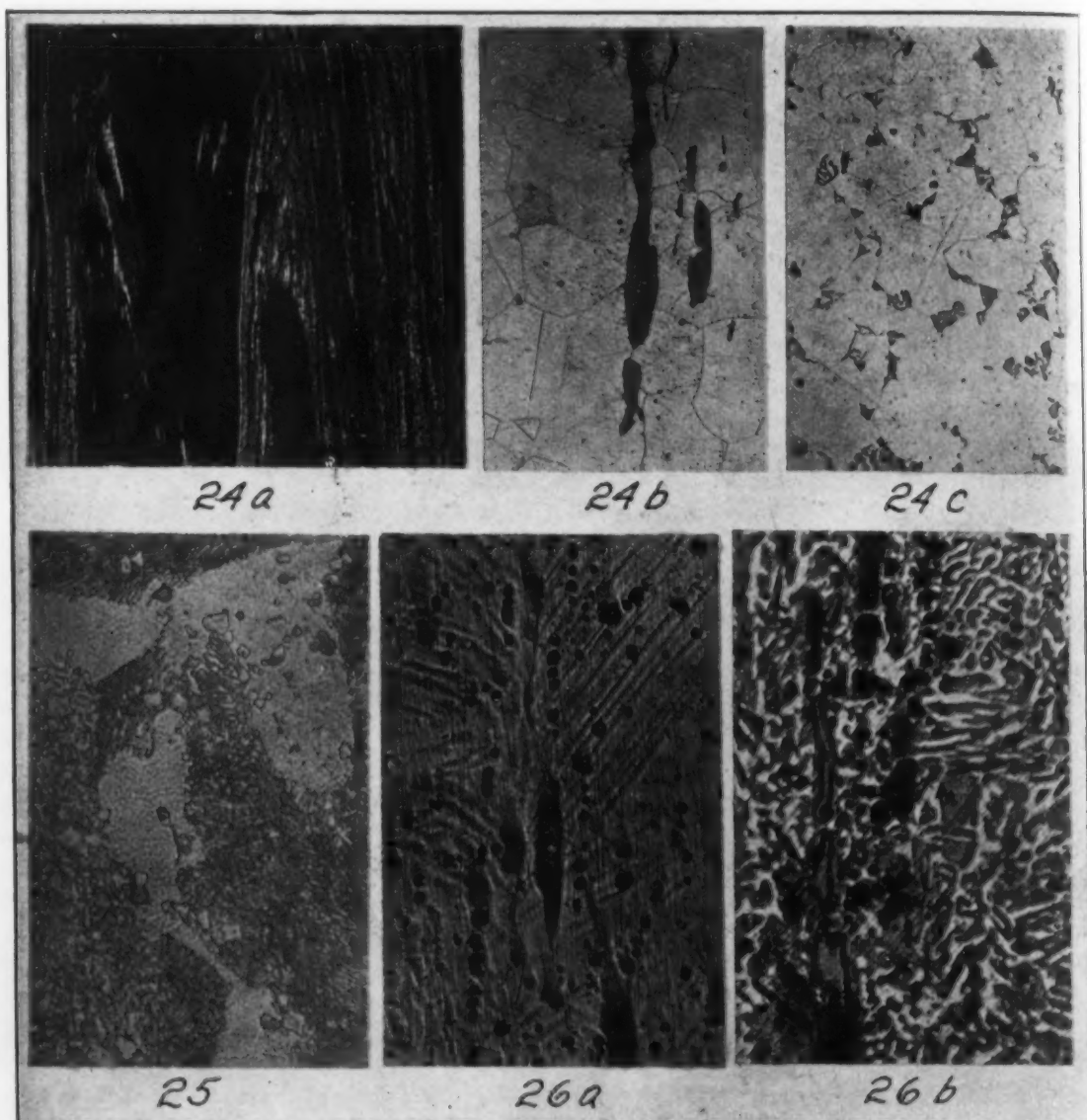
The microscope is often an indispensable means for determining the role played by certain additions made to alloys in the course of the preparation. This is true particularly for steels. Thus an examination of the structure of titanium-treated steels shows that this element, titanium, in the quantities usually added to steel does not alloy with the metal in the sense that many added elements do. Its role is to free the metal of undesirable substances present and then leave the metal in the slag, carrying the detrimental substance combined with it. It appears to be especially active in combining with nitrogen. Zirconium appears to act in a manner similar to that of titanium when added to steel in small amounts, in that it frees the metal from some undesirable substance (not necessarily nitrogen) and then escapes from the metal in some combined form in the slag. The inclusions which are found in zirconium-treated steel are of a very characteristic shape and yellow color (Fig. 25). On the other hand, the primary role of many other added elements



Figs. 22a-22c—Structure of a defective nickel steel forging caused by improper melting practice. Fig. 22a—Macrostructure of a longitudinal section, deeply etched with concentrated hydrochloric acid, showing the core due to the nondiffusion of nickel in the molten steel. $\times 1$. Fig. 22b—Microstructure of specimen Fig. 22a, as received from the mill, outside the core. $\times 100$. Fig. 22c—Microstructure of the core of specimen Fig. 22a, as received from the mill. The nickel content of this part was so high that it remained martensitic even upon slow cooling. $\times 500$. Etching reagent, Fig. 22b and 22c, 2 per cent alcoholic solution of nitric acid. Figs. 23a-23b—Microstructure of complex metallic coatings produced by electrolytic deposition. Fig. 23a—Cross-section of a "brass" coating used on a steel base; the coating consists of three layers, the intermediate one being of nickel, $\times 500$. Fig. 23b—Cross section of an electrolytic deposit consisting of alternate layers of nickel (light) and copper (crystalline), the metal being deposited in the direction shown by the arrow. $\times 100$. Etching reagent, ammonium hydroxide and hydrogen peroxide.

is to react with the steel and to modify the properties, either of the ferrite as in the case of nickel, or the carbide as in the case of chromium.

The form in which certain elements occur in steel and their distribu-



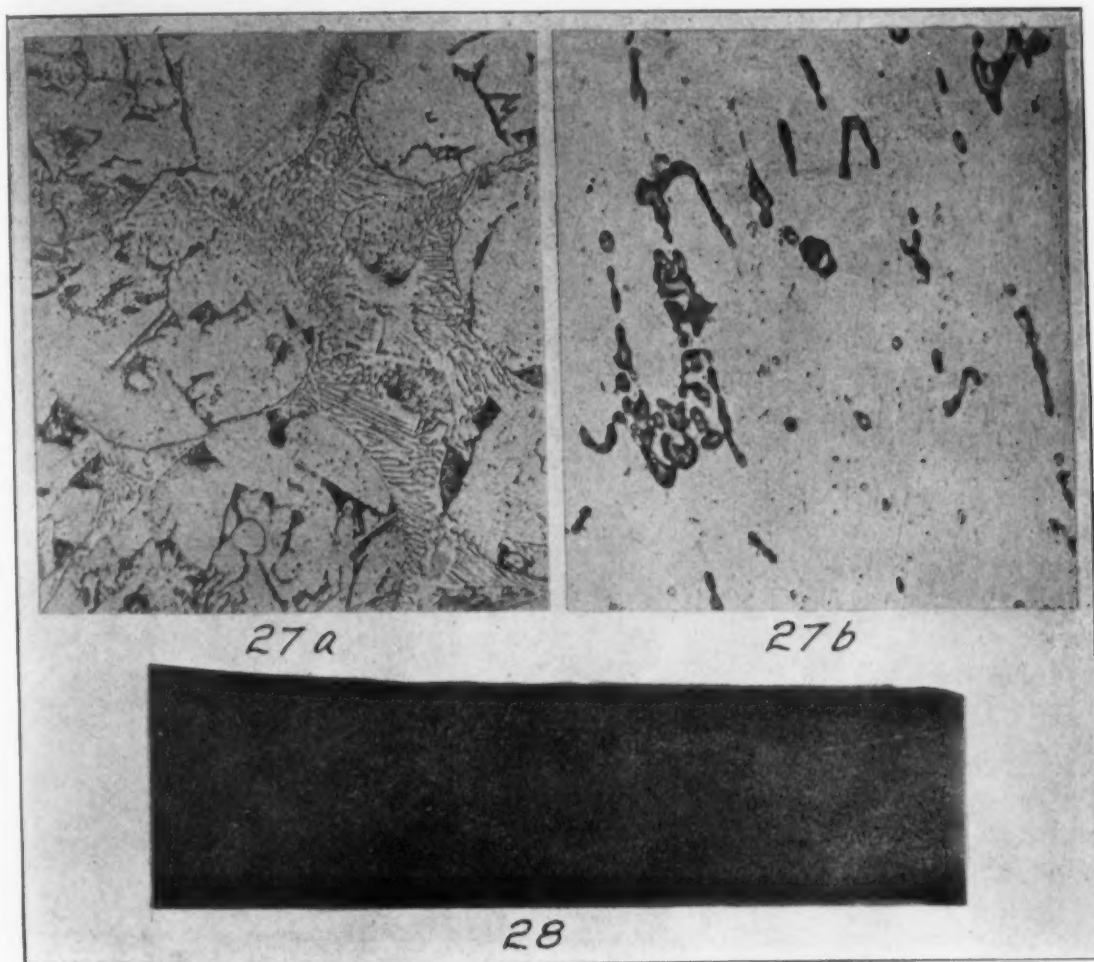
Figs. 24a-24c—Structure of wrought iron to which additions of steel have been made. Fig. 24a—Macrostructure of a longitudinal section of a 2-inch round bar of wrought iron, deeply etched with hot concentrated hydrochloric acid. $\times 1$. The white streaks represent the additions of steel. Fig. 24b—Microstructure of the metal of the dark portions of Fig. 24a. This has the characteristic structure of wrought iron. $\times 100$. Fig. 24c—Microstructure of the metal of one of the light streaks of Fig. 24a. The metal is low-carbon steel. $\times 100$. Etching reagent, 2 per cent alcoholic solution of nitric acid. Fig. 25—Microstructure of steel to which additions of zirconium have been made. $\times 500$. The small light-colored inclusions, square or triangular in outline, are characteristic of steel to which zirconium has been added. They are of a striking lemon-yellow color. Etching reagent, 2 per cent alcoholic solution of nitric acid. Figs. 26a-26b—Microstructure of wrought iron of high phosphorus content, showing the lack of uniform distribution of this element even within the individual crystals. $\times 100$. 26a—Longitudinal section of wrought iron, high in phosphorus (0.36 per cent) annealed at 600 degrees Cent. The phosphorus banding within the individual grains has persisted after this treatment; etching reagent, 10 per cent alcoholic solution of nitric acid. 26b—Longitudinal section of high phosphorus wrought iron, etched with acidified solution of cupric chloride. (Stead's reagent.)

tion throughout the metal are often of much more importance, as far as the properties of the metal are concerned, than the percentage of the element present. This has already been mentioned in the case of sulphur. Phosphorus in the amount usually present in iron and steel, exists in solid solution in the ferrite. The distribution is often far from uniform throughout the metal, and even within the individual crystals the distribution may be far from uniform as is shown in Fig. 26.

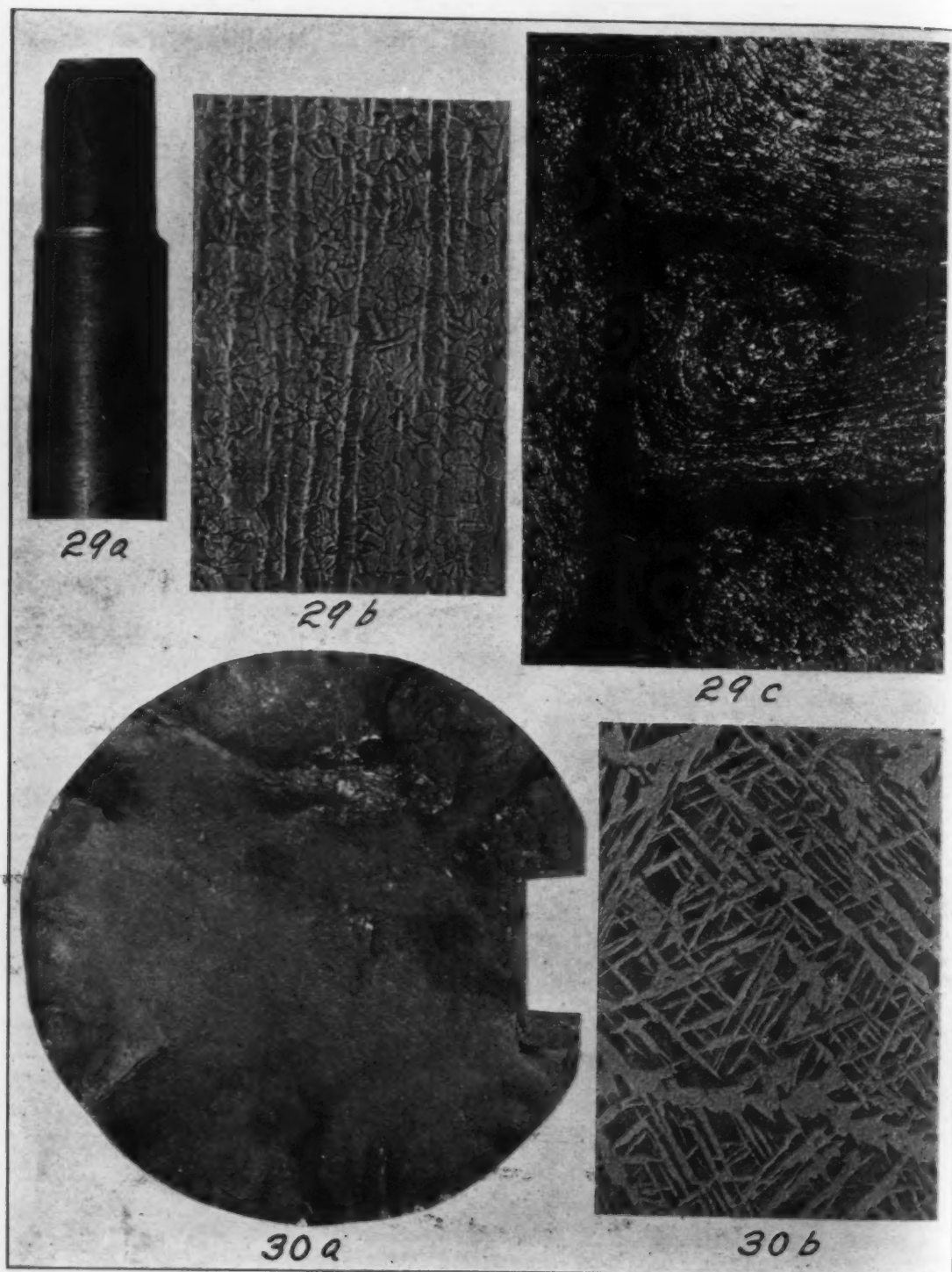
Control of Metallurgical Operations and Products

A knowledge of the structure of an alloy, particularly a new one, will often aid materially in carrying out the mechanical working of the material satisfactorily. Fig. 27 shows the structure of a boron steel. When the attempt was made to roll this steel under the same conditions used with satisfactory results for steels of similar composition but containing no boron, the metal crumbled and cracked badly in the rolls. Indeed, some ingots were so brittle that they broke under their own weight when carried from the furnace to the rolls. By heating the ingots for a sufficiently long time until considerable coalescence of the eutectic occurred and by reducing the temperature of the ingot somewhat, that is, below the eutectic temperature, no unusual difficulties on working the metal were encountered.

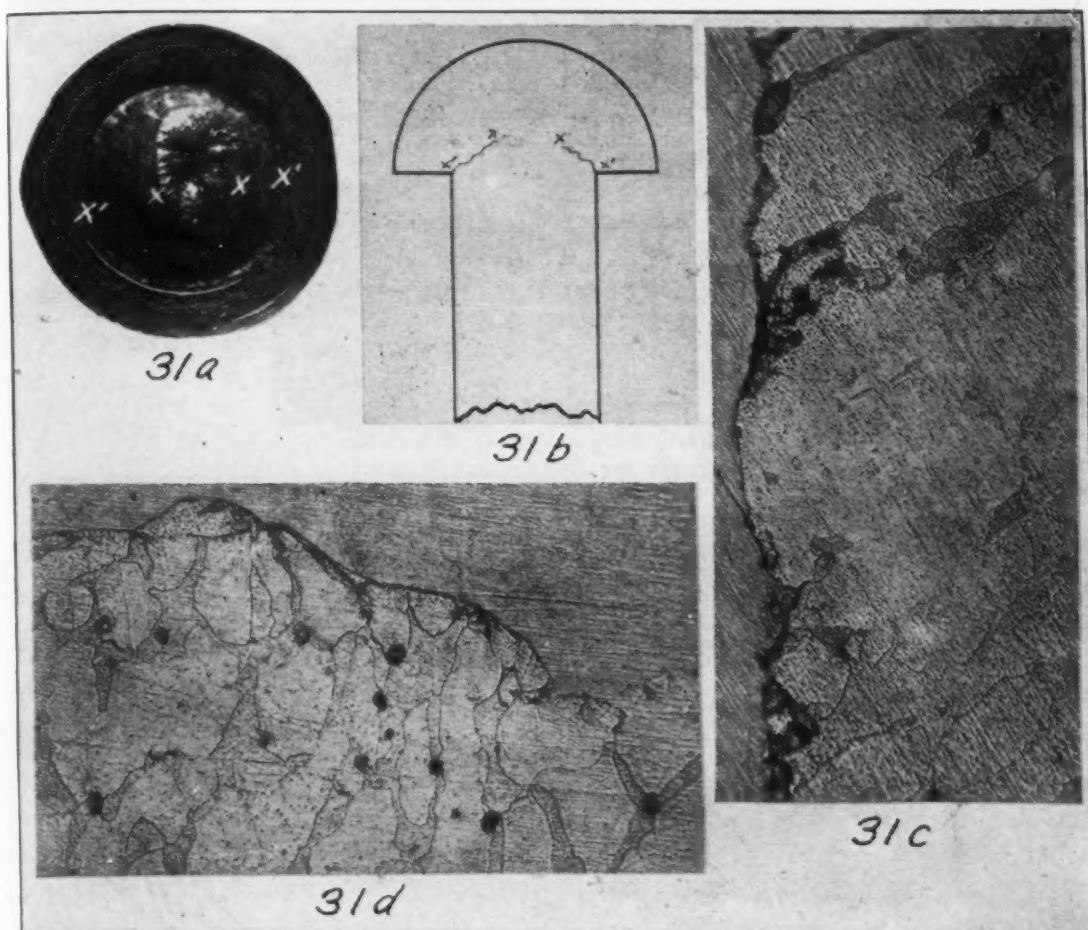
The microscope is often valuable in determining the nature of certain metallurgical products masquerading under misleading names. Thus for example, the nature of wrought iron can be established with certainty by this



Figs. 27a-27b—Microstructure of low-carbon steels to which additions of boron have been made. $\times 500$. Fig. 27a—Section of an ingot of boron steel (carbon 0.16 per cent, boron 0.49 per cent) which broke in the rolls and could not be worked. The addition of the boron causes the formation of the eutectic shown; etching reagent, 2 per cent alcoholic solution of nitric acid. Fig. 27b—Longitudinal section of a rolled plate of boron steel (carbon 0.16 per cent, boron 0.39 per cent) showing the coalescence of the eutectoid which has occurred. Etching reagent, hot alkaline solution of sodium picrate. This reagent colors the carbide a dark brown and sometimes nearly black. Fig. 28—Macrostructure of a steel block showing surface changes caused by cutting the steel by means of the acetylene flame. $\times 1$. The surface has been appreciably hardened for a considerable depth by the chilling action of the cool metal of the interior upon the hot metal of the surface after the flame was withdrawn; etching reagent, aqueous solution of ammonium persulphate.



Figs. 29a-29c—Structure of monel metal showing interior defects originating before the metal was rolled. Fig. 29a—Monel metal rod showing an internal flaw. $\times 1$. Fig. 29b—Longitudinal section of sound monel metal showing "work lines." $\times 100$. Fig. 29c—Section through the defect in specimen Fig. 29a. The distortion of the "work lines" in the neighborhood of the defect proves that the defect existed in the metal previous to the rolling of it. $\times 50$. Etching reagent, Figs. 29b and 29c, concentrated nitric acid. Figs. 30a and 30b—Structure of a steel shafting which failed in service by fatigue. Fig. 30a—Face of the fracture, which originated in a key-way, $\times \frac{1}{4}$. Fig. 30b—Microstructure of the metal of the interior. $\times 50$. Evidently the forging received no treatment for grain refinement; etching reagent 2 per cent alcoholic solution of nitric acid.

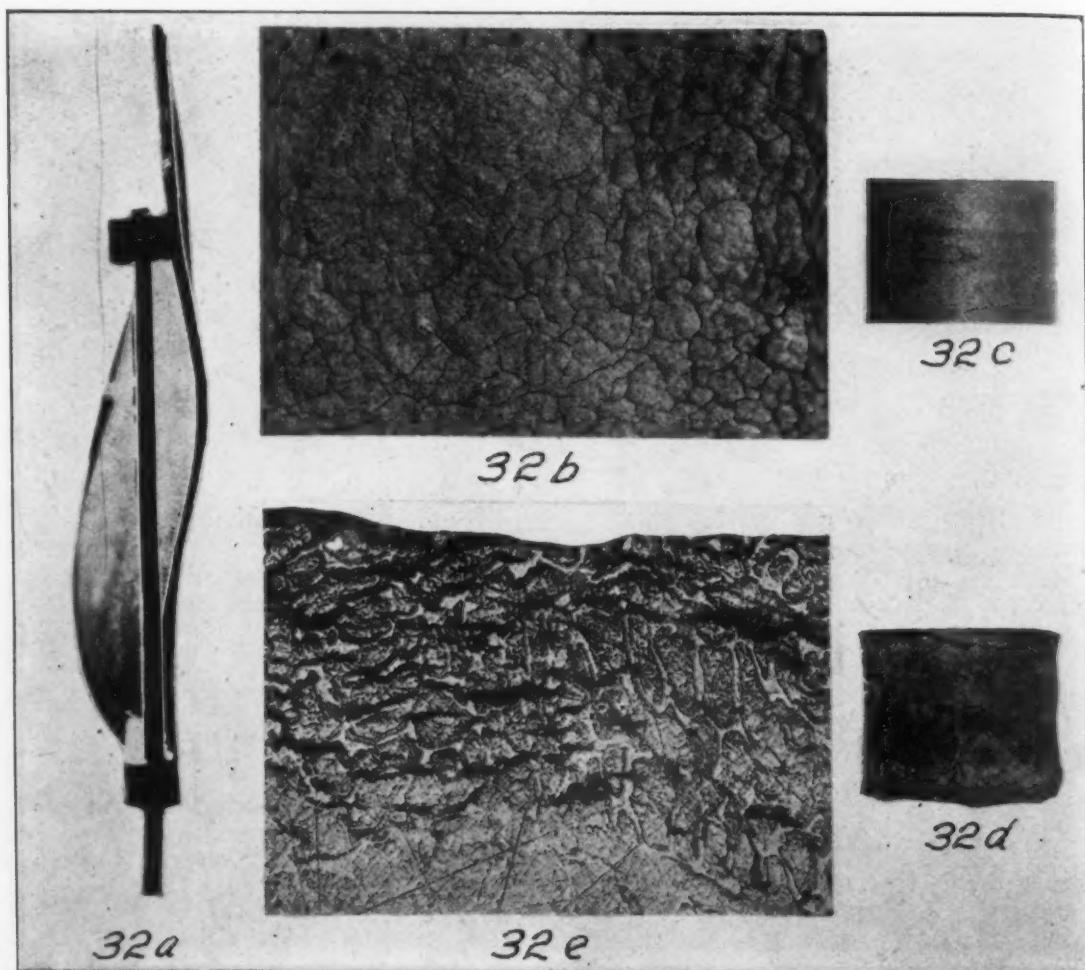


Figs. 31a-31d—Structure of a brass (muntz metal) bolt which failed in service, evidently by being corroded while stressed in tension. Fig. 31a—Fractured face of the bolt-head which dropped off “of its own accord.” $\times 1$. Fig. 31b—Sketch of longitudinal section of the bolt just before the head was detached. Fig. 31c—Microstructure of the metal at the fracture in the portion $x-x'$ of Fig. 31a and 31b. The beta constituent has been dezincified by the corrosive action of sea water to a considerable depth (black in micrograph) by corrosion. $\times 250$. Fig. 31d—Microstructure of the metal at the fracture in the central portion, $x-x'$ in Figs. 31a and 31b. No corrosion has occurred here, tensile stress alone caused the fracture of the part. $\times 250$. Etching reagent, ammonium hydroxide.

means; semisteel can be shown to be only a particular grade of cast iron, having none of the characteristic properties of steel. An interesting example which may be cited is that of a specially prepared copper advertised and sold as a deoxidizer for copper and other alloys. The examination of the material showed that the deoxidizer itself, contained very appreciable amounts of cuprous oxide. “The special treatment” given the material to render it a deoxidizer was not sufficient to prevent oxidation of the metal itself from occurring during the process of treatment. It is difficult to see how such a substance then would have much effect as a deoxidizer when added to other metals.

Certain metallurgical processes are most readily and surely controlled by means of examinations of the structure of the product at various stages of the process. The manufacture of malleable iron offers a good example of this as well as the converse of this, the cementation process.

Fig. 28 shows a block of steel which has been cut by the oxyacetylene flame. The surface change in the metal, which at first sight might be mistaken for a carburized layer, is due to the “quenching” action of the cold



Figs. 32a and 31e—Appearance of certain aluminum alloys of high zinc content after deterioration. Fig. 32a—Fuse box cover, approximate composition; aluminum, 15 per cent; lead, 0.4 per cent; zinc remainder, which was used in a tropical climate and warped in service. $\times \frac{1}{4}$. Fig. 32b—Surface of specimen, showing "alligator cracks." $\times 1$. Fig. 32c—Cylinder of an alloy, composition: copper, 1.4 per cent; aluminum, 15.2 per cent; zinc, 83.4 per cent, exposed to "dry heat" (100 degrees Cent.) for six days. The dimensions of the specimen remained unchanged. $\times 1\frac{1}{2}$. Fig. 32d—Specimen similar to Fig. 32c exposed to "moist heat" 100 degrees Cent., for six days. The specimen expanded and cracked. $\times 1\frac{1}{2}$. Fig. 32e—Cross-section of specimen similar to Fig. 32d, showing the "expansion cracks" which formed in the metal near the surface by the action of heat and moisture; most of these occur in the eutectic; the specimen was unetched. $\times 100$.

metal of the interior upon the hot metal at the surface after the removal of the flame. This special application of the action of a flame upon steel has been perfected, patented and successfully applied in the surface hardening of complex steel shapes, which would be distorted or would crack if hardened in the usual manner.

In the study of the mechanical working of metals it is often necessary to follow the material through the various stages through which it passes. In this connection the chemical nonhomogeneity of metal, for instance, phosphorus-banding as has been indicated previously serves a useful purpose, other structural features often answer the purposes in other alloys, thus, as is shown in Fig. 29, certain discontinuities within a wrought round bar of monel metal were clearly shown by the characteristic *work lines* to have had their origin while the metal was in a plastic state and not to have been produced by any treatment given the material subsequently by the user.

Failure of Metals in Service

In the investigation of the failure of metals which has occurred during service the microscope has proved a very valuable aid and the structure often reveals evidence which the ordinary methods of testing fail to detect entirely. To discuss the relation of the microstructure to the failure of metals is manifestly impossible here, brief references only to a few specific cases will be used as examples.

Fig. 30 shows the appearance of a fracture which occurred in service in a 10-inch steel shafting. The fracture had the characteristic appearance of a *detail* or *fatigue* break which started in the angle of a key-way. The examination of the structure showed that it was almost a perfect one for such a failure, for the particular composition of steel used. Evidently the material had received no annealing treatment whatever for grain refinement after the forging of the shaft was completed. The large crystals with their prominent Widmanstätten structure are almost perfect, so far as failure to withstand repeated or vibratory stresses is concerned.

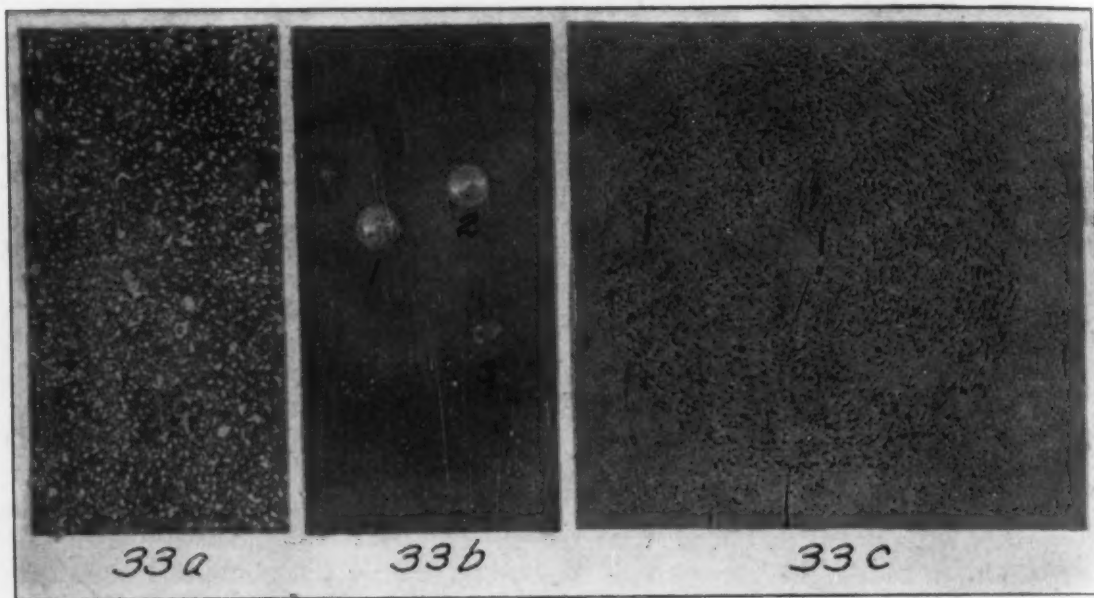
Fig. 31 shows the fractured face of a Muntz metal bolt head which dropped off in service "of its own accord." Examination of the microstructure showed that the failure was due to selective corrosion of the zinc-rich or β constituent was localized at the apex of the angle between the shank and head and accelerated by the service stress carried by the bolt. It can readily be shown that corrosion of such alloys at the apex of a narrow groove, is much more intense than elsewhere in the same material, when the specimen is subjected to a tensile stress while surrounded by the corroding agent, for example, sea water. This behavior is to be attributed to the fact that the stress carried is not distributed equally in all cross sections but is much higher at the bottom of the V-groove, than elsewhere. Under the combined action of corrosion due to sea water and the service tensile stress carried by the bolt, the portion of the fracture $x-x'$ was gradually produced, this has the appearance of a *detail* or *fatigue* break. When the cross-sectional area became small enough so as to break under the applied loading the central portion broke as a simple tensional break. The microstructure of the two portions confirms this; in the portion $x-x'$, the β constituent at the fractured edge of the material shows evidence of deterioration by dezincification while in the central portion the alloy is sound and unchanged up to the extreme edge of the fracture.

Service Deterioration of Alloys

It sometimes happens that an alloy used for some specific purpose deteriorates, usually in a chemical way, under the peculiar conditions to which it is exposed, although for other purposes and for other conditions the material is suitable in every respect. The material of Fig. 32 an alloy of aluminum and zinc was used in a tropical climate and hence was exposed to conditions of high humidity and temperature. The specimen shown, a fuse-box cover, originally flat, warped severely and bent out of shape. The surface showed characteristic "alligator cracks." Fig. 32c shows the appearance of two test specimens of a somewhat similar alloy intended for die castings after exposure to dry and to moist heat (100 degrees Cent.). Heat, in the absence of moisture, had no appreciable effect upon the material, the specimen retained its initial dimensions and shape. The sample exposed to the combined action of heat and moisture, however, rapidly deteriorated by permanent expansion and distortion of the piece. An appreciable increase of hardness also accompanied this change. Microscopic examination showed

that the eutectic was the portion attacked. Presumably oxidation takes place with accompanying increase of volume, the presence of moisture being necessary for this change to occur.

A somewhat similar change sometimes occurs in the filling used for fusible boiler plugs. The filling prescribed for such plugs is very high grade tin. The presence of impurities in small amounts, particularly zinc, has been found to stimulate the oxidation of the tin filling so that in time the plug filling may become a hard infusible mass of oxide. In this case, as the



Figs. 33a-33c—Appearance of the etched surface of a ball used in Brinell hardness determinations and the indentations produced. Fig. 33a—Etched surface of hardening steel ball (chromium steel) used in Brinell hardness determinations, etching reagent 1 per cent alcoholic nitric acid. The white particles are the globules of carbide and are unattacked by moderate etching. $\times 500$. Fig. 33b—Brinell indentations produced on a polished specimen of file steel (carbon approximately 1.4 per cent), with a load of 1000 kilograms applied for 30 seconds on a 10 millimeter ball. Numbers 1 and 2 were obtained with an etched ball, No. 3 with a polished ball. The irregular spot at No. 3 is an ink mark for identification. $\times 3$. Fig. 33c—Indentation No. 1 of Fig. 33b. $\times 50$. The matt appearance of the indentations, Nos. 1 and 2, of Fig. 33b, is due to the great number of tiny pits produced by the carbide particles, which cover the face of the indentation. The indentation shows two distinct concentric zones, apparently due to a difference in the pressure transmitted to the steel plate being tested.

above, the eutectic is the constituent which is most rapidly attacked and oxidized under the combined action of heat and moisture. A very considerable increase in volume accompanies the change in the tin filling of such plugs.

The terminals in spark plugs are very often made of nickel wire, and severe deterioration sometimes occurs. These nickel terminals show more or less deterioration in all spark plugs on account of the high temperature and perhaps to other conditions accompanying their use. This deterioration consists of an intercrystalline attack which may in time develop into visible intercrystalline fissures or cracks. A study made of various types of spark plugs showed that in plugs of certain design the nickel terminals were subject to more or less tensional stress while hot, and in such cases the deterioration was very pronounced, very deeply penetrating cracks formed which soon completely severed the entire wire. It was shown by the microscopic examination of similar wires which had been subjected to the combined action of tensional stress and heat that the material deteriorated in a manner identical in appearance with that of the terminals of the spark plugs produced in service.

Miscellaneous

A knowledge of the microstructure of metals may also be useful in a great number of miscellaneous ways, only one of which, however, will be mentioned here, the application of microstructure in Brinell hardness determinations. Fig. 33 shows how advantage may be taken of the etching properties of the material of the steel ball used in the Brinell hardness test in order to obtain a higher degree of accuracy in the results obtained when testing hard materials. The impression of the ball upon the surface of a hard metal, particularly if the latter is polished, is very indefinite and the measuring of the diameter of the impression is a matter entailing considerable uncertainty. The ball used for the purpose consists practically always of a chromium steel of such a composition that in the hardened state it contains free carbide in the form of numerous rounded particles. By etching the ball slightly before use (2 minutes' immersion in one per cent alcoholic nitric acid) the "flowed metal" on the polished surface can be removed and the hard carbide particles revealed. An impression made with such an etched ball upon a polished surface of a hardened steel is very much more conspicuous than one obtained with a polished one. When the high pressure is applied, the carbide particles produce a multitude of tiny pits over the surface of the indentation of the ball, thus giving a *matt-finish* to the indentation which aids very materially in defining its limits.

Many other cases might be cited of practical applications of the microscopy of metals. It is believed, however, that from what has been given it is quite evident that the metallurgical microscope is one of the most useful aids at one's disposal in the study and testing of metals.

NOTES FROM THE BUREAU OF STANDARDS

Apparatus for the Determination of the Magnetic Properties of Short Bars

THE growing interest among engineers and designers in the correlation of the magnetic and other physical properties of iron and steel has given impetus to the study and development of methods for making the necessary magnetic measurements. Many materials of an experimental composition or of extreme purity are available only in limited quantities, and the ability to obtain magnetic measurements on small samples would be of decided advantage both from the point of view of economy of material and because of the ease of the machining and heat treatment.

The direct determination of the magnetic properties of small samples with any degree of accuracy is a difficult matter, but the Bureau of Standards has recently developed an apparatus capable of measuring the magnetic properties of such a sample with a satisfactory degree of precision. The method involves the comparison of a sample of the material to be tested, which is in the form of a cylindrical bar 6 millimeters in diameter and 10 centimeters long, with a reference bar, the apparent magnetic properties of which have been determined through calibration by means of standard bars having accurately known properties. This method is capable of giving results accurate within 5 per cent for most materials. As the accuracy depends, to some extent, upon the degree with which the properties of the test bar agree with those of the standard bar used for the calibration. The range of materials which can be tested with satisfactory accuracy depends upon the range of the properties covered by the series of standard bars. This work will be found described in Scientific Paper No. 448 of the Bureau of Standards.

Effect of Temperature, Deformation, and Rate of Loading on the Tensile Properties of Low Carbon Steel Below the Thermal Critical Range

The metallurgical laboratories of the Bureau of Standards have been conducting tests on the properties of various grades of boiler plate through the range of 20 to 465 degrees Cent. This has been carried on to determine the effects of blue and cold work, variations in rate of loading, elastic overstrain, and subsequent behavior of the overstrained steel with time. The results of this work have been published in Technologic Paper No. 219.

The paper describes the special apparatus employed for making high temperature tensile tests and the differences in behavior of the steel which were noted in various temperature ranges. It was found that the proportional limit of the several grades of plates does not decrease with the first rise in temperature but is either maintained at about room temperature value or increases before the final decrease occurs.

The increased strength produced by rolling cold or at blue heat (300 degrees Cent.) is maintained throughout a considerable temperature range, but these effects may be removed by suitable annealing. High proportional limit exists while tempering cold rolled plate at 300 degrees Cent. or after cooling to room temperature, an effect which

can be used to advantage in the production of cold finished products, such as thin walled seamless steel tubes where bluing after the final cold pass will produce a high elastic ratio.

Some effects of tensional elastic overstrain are also described in detail. Among the tests made are those showing that the proportional limit can be made to approximate the tensile strength by overstraining successively at blue heat with gradually increasing loads. Differences in behavior of overstrained steel upon etching are observed depending upon whether the overload is applied above 465 degrees Cent. or below blue heat (300 degrees Cent.). Likewise, the effect of decrease in rate of loading is different in these two temperature ranges, though little variation in tensile properties was observed when tests were performed 30 times as fast as would ordinarily be the case.

Wear of Steels

Several tests have been conducted by the Bureau of Standards to determine the resistance to wear of hardened and tempered chromium steels. It was noticed that while the so-called standard hardened specimen, which was run on the upper shaft of the testing apparatus, invariably had a polished surface at the conclusion of every test, the bottom specimen, especially the tempered specimens, presented a dull appearance which was presumed to be caused by abraded articles sticking to the specimen. It seemed, therefore, that specimens with this dull mottled appearance would show a loss of weight less than the actual loss. To prove this several tests were made of Ketos steel running the standard hardened specimen on the lower shaft and the tempered specimens on the upper shaft. The curve of rate of wear versus tempering temperature obtained was similar to the previous curve but showed a greater rate of wear.

The tempered specimens under the last-named conditions were free from abraded material at the end of the tests. Efforts will be made to prevent the adherence of the abraded metal particles to the specimen.

The Effect of the Presence of Oxygen in Iron-Carbon-Manganese-Sulphur Alloys Upon the Forging Properties

A short series of iron-sulphur-manganese alloys has been prepared by melting under air, for comparison with a portion of a similar series prepared in the Arsem vacuum furnace, in order to determine whether the presence of oxygen in the alloy influences the sulphur limit and the manganese sulphur ratio for successful forging.

It has been necessary to develop a new type of refractory crucible for use in preparing the carbon alloys of the vacuum-fused series of this investigation. Manganese crucibles are not desirable on account of the slagging out of sulphur.

Zirconium silicate crucibles served satisfactorily for the preparation of the iron-sulphur and iron-sulphur-manganese alloys, but with the ad-

dition of carbon, the alloys are contaminated by silicon. Tests are now in progress to determine the suitability of a crucible made chiefly of zirconium oxide.

Tests of Thermocouples

Life tests of the pure platinum and platinum-rhodium wire prepared at the Bureau of Standards for thermocouples have been carried out by the heat division. These tests are the same as those applied to commercial couples which were recently reported by Fairchild and Schmitt in *Chemical and Metallurgical Engineering*. Results thus far obtained indicate that couples of material purified, melted and drawn to wire at the Bureau are appreciably superior to the best commercial couples previously tested. A paper describing the preparation and life tests of such couples has been written and will be offered for presentation at the spring meeting of the American Electro-chemical Society. Another paper describing the general platinum metals investigations, now in progress at the Bureau, has also been prepared for presentation at the same meeting.

Routine Magnetic Testing

The routine magnetic testing of the Bureau has been placed upon a new basis which provides for two classes of test. Class A will be restricted to specimens which are sufficiently uniform in dimensions and magnetic properties along their length to justify the employment of test methods of the highest accuracy and which are intended for use as standards for the calibration of testing apparatus, or for other uses where high precision is necessary. For this class of test, two specimens are required of the same material, one of which is used as an auxiliary. Class B test will be made in general in cases where the material is not sufficiently uniform to justify the use of precision methods or where the highest accuracy is not necessary.

Cutting Tests of High Speed Steel

Five types of steel are to be considered in this investigation, and the second steel of the series has been heat treated for the first set of tests in which hardening temperature is the variable. In connection with this work a number of treatments were applied to a single heat of high-tungsten low-vanadium steel to determine whether so-called fish scale or flaky fractures could be produced intentionally irrespective of the quality of metal as has been claimed. Normal fractures were obtained, however, in all cases, but these tests will be supplemented by further work with steel of questionable quality. The question was brought up for discussion at a recent meeting of the American Society for Steel Treating at Rockford, Illinois.

Erection of a 10,000,000-Pound Testing Machine

For many years a small branch of the Bureau of Standards has been maintained in Pittsburgh for the testing of structural materials. Recently it was decided to concentrate all of this work in Washington with the result that for some months past the equipment of the Pittsburgh laboratory has been in process of removal from its old site to the permanent location at the Bureau.

An interesting part of this work has been the transportation and

erection of the 10,000,000-pound Olsen testing machine. This work is now completed and the machine has been calibrated and is now ready for use. Advantage was taken of the dismantling of this machine to prepare complete drawings of the various parts for future use.

Etching Reagents for Alloy Steels

Considerable attention was paid during the past month to the problem of finding an etching reagent by which chromium carbide could be distinguished from vanadium carbide in a positive and satisfactory manner. Only one out of about 20 of the reagents tried seemed likely to be of much use in this connection. This is a hot solution of potassium permanganate and sodium hydroxide, etching in which for one minute darkens chromium carbide to a strong brown-red or brown color, or rather, the carbon is eaten out giving the walls of the cavity thus formed a dark brown-red color, while vanadium carbide remains uncolored and apparently unattacked.

Another but less positive means of distinction is that obtained by electrolytic etching with a weak current in a dilute aqueous solution of ammonia or sodium hydroxide. The chromium carbide is eaten out leaving a dark brown-red or brown cavity, while the vanadium carbide is eaten out apparently at a slower rate leaving cavities which appear light and not at all darkened.

Recent Publications of the Bureau of Standards of Especial Interest to Our Readers

Scientific Papers

- S 452 Structure of martensitic carbon steels and changes in micro-structure which occur upon tempering. H. S. Rawdon and Samuel Epstein.
- S 453 Preparation and properties of pure iron alloys: 1. Effects of carbon and manganese on the mechanical properties of pure iron. Robert P. Neville and J. R. Cain.
- S 457 Gases in metals: 1. The determination of combined nitrogen in iron and steel and the change in form of nitrogen by heat treatment. L. Jordan and F. E. Swindells.
- S 458 Apparatus for the determination of the magnetic properties of short bars. M. F. Fischer.

Technologic Papers

- T 219 Effect of temperature, deformation, and rate of loading on the tensile properties of low-carbon steel below the thermal critical range. H. J. French.
- T 221 Magnetic susceptibility and iron content of cast red brasses. L. H. Marshall and R. L. Sanford.

The Question Box

A Column Devoted to the Asking, Answering and Discussing of
Practical Questions in Heat Treatment—Members Submitting
Answers and Discussions Are Requested to Refer to
Serial Numbers of Questions.

NEW QUESTIONS

QUESTION NO. 71. *How do the physical properties compare between a 0.35-0.45 per cent carbon acid open-hearth steel and an alloy steel of either 3.5 per cent nickel or 1.5 per cent nickel and 0.50 per cent chromium neither heat treated?*

QUESTION NO. 72. *What elements are conducive to good electric butt-welding of steels?*

QUESTION NO. 73. *Does electric butt-welding destroy the physical properties developed in a steel which has been heat treated prior to the welding operation?*

QUESTION NO. 74. *Why shouldn't a bar of steel rolled from a locomotive axle be better than one rolled direct from the billet made from the original ingot?*

QUESTION NO. 75. *How much would the cold drawing of any steel affect its hardness when only one or two, light passes are given for the purpose of sizing only?*

ANSWERS TO OLD QUESTIONS

QUESTION NO. 27. *What is the function of the high phosphorus and the high sulphur content in the so-called automatic screw stock steel?*

QUESTION NO. 56. *Which is the best method of producing large forgings, pressing or hammering?*

ANSWER. By John J. Crowe, metallurgist, Philadelphia.

There are practically no differences in the properties of properly hammered or pressed forgings, but the problem resolves itself into one of tool design.

Presses of large capacity are better suited for the working of large forgings and are therefore used. A hammer of same capacity as a 10,000-ton

press would shake windows out of houses within a radius of a mile, whereas, a press can be operated without appreciable vibration.

QUESTION NO. 57 Does repeated heating just above the critical range with subsequent quenching, of a steel specimen injure its physical properties?

ANSWER. By John J. Crowe, metallurgist, Philadelphia.

The repeated heating of ordinary forging steels to just above the critical range with subsequent quenching, does not injure their physical properties, but may under some conditions greatly improve them. Mr. Fry, metallurgist of the Standard Steel Co., has published results on specimens taken from a forging which was originally a six-inch cube, which had been quenched approximately 500 times. The results show the materials to have excellent physical properties and quite strongly indicates that they have not been lowered by the repeated quenchings although the specimen is now almost a sphere instead of a cube. There may, of course, be changes in the surface layer of the metal due to the furnace atmosphere.

QUESTION NO. 59. Is a sulphur content of 0.067 per cent detrimental to the proper carburizing of a low carbon steel having a low manganese and phosphorus content?

QUESTION NO. 62. What is the difference between annealing and normalizing steel?

ANSWER. At times the terms annealing and normalizing are used rather loosely to mean either one or the other of the following definitions. The American Society for Steel Treating has a committee working on nomenclature and this committee will undoubtedly establish definitions of these two terms.

The Society for Automotive Engineering have adopted the following definitions of these terms.

Normalizing.—A uniform heating above the upper critical temperature followed by cooling freely in air.

Annealing.—A uniform heating above the upper critical temperature followed by slow cooling as desired.

QUESTION NO. 64. To what extent can the deep etching of specimens of steel be applied to routine examination of incoming material?

QUESTION NO. 66. What method and procedure is used in brazing Stellite to carbon steel?

QUESTION NO. 67. *What is the reason for the fact that a piece of steel quenched in brine will be harder than the same piece of steel would be if quenched in water, providing that the quenching temperatures and quenching medium temperatures are the same in each case?*

QUESTION NO. 68. *What is the correct temperature of heating for forging, a .40-.50 per cent carbon steel into automobile crankshafts?*

QUESTION NO. 69. *Is sulphur up to .10 per cent detrimental to the quality and physical properties of an automotive steel?*

QUESTION NO. 70. *Is it possible to have a specimen of steel in such a condition that it will show in any one field observed under a microscope at 100 diameters magnification, ferrite, pearlite, sorbite, troostite and cementite?*

Abstracts of Technical Articles

Brief Reviews of Publications of Interest
to Metallurgists and Steel Treaters

SERVICE FOR MEMBERS

The Library Bureau of the American Society for Steel Treating is operated to give to the members quickly, reliably and at the minimum expense the following service:

1. A complete copy of the magazine article referred to in any periodical you may be reading.
2. A translation of foreign articles that would help you with your work.
3. A list of references to books and articles on any metallurgical subject.
4. Informing the members of new articles of interest to them as an engineer.

The Library Bureau makes the entire field of literature available to every member, distance is eliminated, for it will copy the desired information and send it to you. It also helps the busy man by supplying information without any expenditure of his time. The charge for this personal work is merely its cost.

The Library Service does not obtain any profit from the work, but does this to make the information contained in the large libraries with which it has connection available to every member. The rates are as follows:

Photo Print Copies of articles, drawings, etc., 25c per 10 x 14-inch sheets.

Searches, abstracts, etc., \$2.00 an hour.

Translations, \$6.00 per thousand words for French or German; \$7.50 and upward for other languages.

Reference card service, giving reference to current magazine articles, \$10.00 a year in advance, and 5c for each card mailed.

Members desiring to avail themselves of this service should address Library Bureau, American Society for Steel Treating, 4600 Prospect Ave., Cleveland, Ohio.

HEATING AND COOLING LARGE INGOTS. By F. E. Bash, in *Iron Trade Review*, Feb. 22, 1923, page 594.

This article gives the results of experiments which have been made to obtain data for determining the maximum rate of heating ingots without injury, and states that reliable figures are available on twenty-four, thirty and forty-five inch sizes.

CALORIFIC VALUE OF STEEL-MAKING ELEMENTS. By H. D. Hibbard, in *Iron Age*, Vol. 111, No. 5, Feb. 1, 1923, page 347.

In this article the author explains the actions of phosphorus, manganese, chromium and other metals in steel processes, and points out the peculiarities of sulphur.

SPECIFICATIONS FOR DIE-BLOCK STEEL. In *Forging and Heat Treating*, January, 1923, page 47.

The above was taken from the *Drop Forger* (British), November, 1922. This article gives a report of the investigation of the specifications for die-block steel and outlines the desirable fundamental properties. It also gives the effect of alloying elements upon strength, machinability and heat treatment.

STRUCTURE OF CHROMIUM-NICKEL STEEL. By Messrs. H. B. Pulsifer and O. V. Greene, in *Chemical and Metallurgical Engineering*, Vol. 28, No. 8, Feb. 21, 1923, page 354.

In the article are given a series of micrographs which fail to show any change in structure in quenched chromium-nickel steel after various draws, in spite of the large differences in the physical properties. The article also points out the precautions necessary in etching and photographing.

and **NOTES ON THE HEAT TREATMENT OF HIGH-SPEED STEEL.** By H. K. Ogilvie, in February, 1923, *Railway Journal*, page 16.

The above notes were taken from a paper read before the Iron & Steel Institute (British) recently.

The author in presenting his article made some good suggestions stating that it is not good practice to make large, thin cutters direct from forged bars unless the bore of the cutter is extremely wide, it being preferable to use a medium sized ingot and forge it until it is about four or five inches round.

THE MAGNETIC CHANGE A_2 IN SILICON AND CHROMIUM STEELS. By Howard Scott, Associate Physicist, Bureau of Standards. In Vol. 28, No. 5, Jan. 31, 1923, *Chemical and Metallurgical Engineering*, page 212-215.

In the above article the author points out that since the carbon change points is at a higher temperature than the magnetic change point, it is impossible to rely upon the loss of magnetism to indicate the proper hardening temperatures for silicon and chromium steels. Several tables are given showing the inverse rate heating curves of silicon and chromium steels.

X-RAY EXAMINATION OF STEEL CASTINGS. By H. H. Lester, Watertown Arsenal, in *Chemical and Metallurgical Engineering*, Vol. 28, No. 6, Feb. 7, 1923, page 261.

The above article states that it is possible to locate 1/16-inch flaws in steel three inches thick with a 30-minute exposure from a commercial X-ray tube, and also that correspondingly smaller defects can be likewise revealed in thinner sections.

COMPOSITION AND MANUFACTURE OF DIE-BLOCK STEEL. By Chas. McKnight, International Nickel Co., New York City, in *Forging and Heat Treating*, January, 1923, page 44.

This article discusses the merits of various steels used for die-blocks and compares straight carbon and alloy steels. It also points out the importance of careful heat treatment.

EFFICIENT CASE HARDENING BOXES. By L. C. Dunn, Montgomery Chemical Co., Detroit, Mich., in *Forging and Heat Treating*, January, 1923, page 53.

The above article points out that the design of efficient case hardening boxes varies according to the type of furnace and the work to be treated. It also compares plain carbon and alloy boxes.

HEAT TREATMENT AND THE STRENGTH OF STEEL UNDER REPEATED STRESSES. By J. W. Harsch, University of Illinois, in *Forging and Heat Treating*, January, 1923, page 57.

In the above article the author discusses the effect of heat treatment on the fatigue strength of steel, and describes in detail machines and methods. He also points out the influence of structure on fatigue resisting properties.

THE METALLURGICAL MICROSCOPE. By Dr. Walter M. Mitchell, Philadelphia, Pa., in *Forging and Heat Treating*, January, 1923, page 63.

This is part 1 of a series of articles to be written on this subject. The article discusses the microscope as applied to the examination of metallic specimens. It also explains at considerable length the use and limitations of the various lenses.

THE AUTOMATIC CONTROL OF TEMPERATURE IN INDUSTRIAL FURNACES. By Messrs. W. Trinks and S. A. Henderson, Carnregie Institute of Technology, in *Forging and Heat Treating*, January, 1923, page 68.

This article discusses in detail the various types of automatic temperature controls as applied to furnaces heated by electricity, gas or oil. It also points out the importance of the location of the thermo-couple.

STRESS IN ELECTRIC-RAILWAY MOTOR PINIONS. By Messrs. Paul Heymans, Cambridge, Mass., and A. L. Kimball Jr., Schenectady, N. Y., in *Mechanical Engineering*, Vol. 45 No. 2, February, 1923, page 93-96.

The above article includes the results of a scientific study taken by the General Electric Co., for the development of superior electric railway motor pinions. The work was performed at Massachusetts Institute of Technology using apparatus belonging to General Electric Co. for stress determination in transparent models by the photo-elastic method. Some of the tests were made at Schenectady and close contact was kept with the railway motor department and the research laboratory at Schenectady. A description and discussion of the photo-elastic method is given, and the causes of ruptures of given types of gear pinions used in electric-railway motors are discussed.

THERMAL PROPERTIES OF ALUMINUM-SILICON ALLOYS. By Junius D. Edwards, Assistant Director of Research, Aluminum Co. of America, in *Chemical and Metallurgical Engineering*, Vol. 28, No. 4, January, 1923, pages 165-169

In this article is given the accurate determination of the densities of aluminum alloys containing variable amounts of silicon. It also gives data on crystallization shrinkage as well as the total solid shrinkage and the tendency to form pipes.

OSCILLATIONS AND FATIGUE OF SPRINGS. By Joseph Kaye Wood, Western Electric Co. In *American Machinist*, Vol. 58, No. 4, Jan. 25, 1923, pages 155-159.

This article points out that internal friction is the chief cause of fatigue. It also shows that there are two resistances in hysteresis. This article gives also the practical uses of overstrain.

GRAY IRON CASTINGS FROM THE ELECTRIC FURNACE. By Larry J. Barton, in *Iron Age*, Vol. 111, No. 4, Jan. 25, 1923. Pages 269-273.

The author in the above article explains how it is possible to produce gray iron castings commercially in an electric furnace. He also gives the acid and basic practice and gives the recommended practice, and describes the heat treatment of iron castings.

THE METALLURGY OF SEMISTEEL. By David McLain in *Western Machinery World*, February, 1923, pages 60-63.

The object of the above article is to give some plain proofs about semi-steel, and many of the statements made deal with historical facts dating back fifty years. The article states that the name semi-steel has been misused for many years and will continue to be as long as there is no interest shown to really find out what it is.

FUEL GAS QUESTION IN STEEL INDUSTRY. By F. J. Denk in *Iron Age*, Feb. 8, 1923, page 401.

The article points out that B. t. u. values in comparing fuels can not be depended upon since it has been found that the efficiency of a gaseous fuel does not depend upon its heat value, but upon its pyrometric efficiency. Combustion curves are given, which show the determination and comparison of the gases used mostly in the steel industry. These further show that with the exception of producer gas, natural gas has the lowest flame temperature of the gases taken into consideration. A table is also given which shows the amount of steam which can be raised by waste gases from one pound of coal gasified.

ELECTRIC HEATING ADVANCE RAPID. By F. A. Hansen, Westinghouse Electric & Mfg. Co. In *Iron Trade Review*, Feb. 15, 1923, pages 512-514.

The above article states that much electrical heating in the iron and steel industry has taken place in the past few years, and further points that the principal advantages of electricity for operating are that it is economical, clean, and easy to take care of.

OFFERS FIELD FOR ELECTRIC FURNACES. By Lansing W. Hoyt, Trade Commissioner, Shanghai, China. In *Iron Trade Review*, Feb. 15, 1923, page 515.

The author of this article discusses the iron and steel situation in China, and states that Shanghai is able to make electric steel at a moderate cost, and also that castings could be made for less than \$35.00 per ton. There are no steel foundries in China.

News of the Chapters

SCHEDULED REGULAR MEETING NIGHTS

FOR the convenience of visiting members, those chapters having regular meeting nights are listed below. It is desired that all secretaries whose chapters are not included in the list should communicate with the National Office in order that the list may be as complete as possible.

- Boston—Second Tuesday
- Bridgeport—Thursday between 20th and end of month
- Chicago—Second Thursday
- Cincinnati—Second Thursday
- Cleveland—Fourth Friday, Cleveland Engineering Society Rooms, Hotel Winton; meeting at 8:00 p. m.
- Detroit—Second and fourth Monday, Wing E., 15th Floor General Motors building.
- Hartford—Friday nearest 10th of month
- Indianapolis—Second Monday
- Lehigh Valley—No regular night
- New Haven—Third Friday
- New York—Third Wednesday
- Philadelphia—Last Friday
- Pittsburgh—First Tuesday
- Providence—No regular night. Nov. 10th, Dec. 12th.
- Schenectady—Third Tuesday
- Springfield—Third Friday
- South Bend—Second Wednesday
- St. Louis—Third Monday
- Syracuse—No regular night
- Tri City—Thursday
- Washington—Third Friday
- Rockford—Second Friday following the second Thursday

MEMBERSHIP AND ATTENDANCE CONTEST

The following arrangement of the chapters shows the percentage of increase of new members as of Feb. 1, 1923, based on the number of members each chapter had on Sept. 1, 1922. While practically all of the chapters have shown an increase in membership over that given in the last report, those printed in CAPS have passed others.

Per Cent		Per Cent		Per Cent	
1. Detroit	56.1	10. Buffalo	22.5	19. Chicago	12.0
2. NORTH WEST	48.0	11. CINCINNATI	18.9	20. Pittsburgh	10.4
3. South Bend	44.0	12. New York	18.1	21. Springfield	10.3
4. Boston	35.0	13. Syracuse	16.4	22. ST. LOUIS	9.6
5. TRI CITY	34.2	14. Cleveland	16.1	23. NEW HAVEN	9.1
6. Philadelphia	32.0	15. WASHINGTON	15.0	24. Worcester	8.9
7. SCHENCTADY	29.4	16. Rockford	14.6	25. Toronto	7.2
8. Lehigh Valley	26.8	17. Hartford	14.4	26. Rochester	0
9. Milwaukee	26.6	18. Indianapolis	14.3	27. Providence	0

Attendance At January Meetings

Only 18 chapters reported attendance at January meetings consequently only that number is listed below. The report of attendance for 6 meetings is necessary in order to qualify a chapter in the contest.

The following chapters did not report attendance at their January meetings. Boston, Buffalo, Cincinnati, Indianapolis, Lehigh Valley, Rochester, Schenectady, Springfield and Worcester.

New Haven had the largest percentage of members present (56.3 per cent). North West jumped from seventh in December to second place in January; Tri City also showed an advance. All of the chapters had over 30 per cent of their membership present at their January meeting.

The following gives the percentage of attendance at the January meetings of the chapters reporting. Chapters printed in CAPS show an increase in attendance:

	Per Cent		Per Cent		Per Cent
1. NEW HAVEN...	56.3	7. Toronto	43.4	13. CLEVELAND ..	25.6
2. NORTH WEST ..	49.0	8. Rockford	42.0	14. Detroit	22.9
3. SYRACUSE	47.5	9. ST. LOUIS	32.7	15. Chicago	22.0
4. TRI CITY	46.8	10. Hartford	31.4	16. PITTSBURGH ..	17.4
5. South Bend	46.7	11. Philadelphia	30.9	17. Washington	17.0
6. Providence	44.4	12. MILWAUKEE ..	27.5	18. New York	14.5

Standing in the Contest

In order to determine the standing of each chapter in the contest it is necessary to add the percentage of attendance at the December meeting and at the January meeting and divide by 2 to get the average attendance for the two meetings. The average thus obtained is added to the percentage of increase in members obtained since Sept. 1 1922 to Jan. 30. This total is then divided by 2 to obtain the standing of each chapter in the contest inasmuch as attendance counts 50 per cent and increase in membership 50 per cent. For example, a chapter had 50 per cent attendance at December meeting and 60 per cent attendance at the January meeting which gives an average attendance of 55 per cent. The percentage of increase in membership of this chapter was 45 per cent—giving an average standing in the contest of 50 per cent.

On this basis we find the following to be the standing of the chapters on Feb. 1 in the Membership and Attendance Contest:

	Per Cent		Per Cent		Per Cent
1. South Bend	47.3	8. Providence	26.7	15. Cleveland	20.0
2. Detroit	46.0	9. New Haven	26.4	16. St. Louis	20.0
3. North West	44.5	10. Toronto	25.3	17. Washington	17.9
4. Syracuse	39.0	11. Cincinnati	24.2	18. Chicago	17.5
5. Tri City	37.5	12. Hartford	24.2	19. New York	16.7
6. Philadelphia	32.1	13. Milwaukee	23.5	20. Pittsburgh	14.1
7. Rockford	30.0	14. Springfield	21.3		

Never Too Late

As stated in the report in February TRANSACTIONS, it is never too late to get in this contest and land among the winners because several chapters that were not reported in the December report have taken

very high positions in this report. A little concentrated effort and a follow-up system to secure attendance at meetings will obtain desirable results.

New Members

There were 64 new members added to the roll of the society during the past month. This number was increased to 66 by the reinstatement of two members who had been dropped. However, this increase was offset by 29 members being dropped for non payment of dues—11 resignations and 1 death, making a total loss of 41. This leaves a net increase of 25 members.

Keep-Them-In Committee

Many chapters have organized Keep-Them-In committees and as soon as the secretary is notified that several members are in arrears and will be dropped for non payment of dues, this committee gets busy and endeavors to have them retain their membership in the society. It is believed that this committee can be so organized as to do very valuable work.

Based on the number of members in each chapter on Jan. 30 the following table shows the standing of the 27 chapters of the society. Those printed in CAPS have advanced their positions while those in italics have a lower position.

The standing is as follows:

1. Detroit	10. Lehigh Valley	19. CINCINNATI
2. Chicago	11. North West	20. * <i>Buffalo</i>
3. Pittsburgh	12. Syracuse	21. * <i>Schenectady</i>
4. Philadelphia	13. * <i>Worcester</i>	22. Springfield
5. Cleveland	14. * <i>Indianapolis</i>	23. Providence
6. New York	15. St. Louis	24. South Bend
7. Hartford	16. Rockford	25. New Haven
8. BOSTON	17. Tri City	26. Toronto
9. <i>Milwaukee</i>	18. WASHINGTON	27. Rochester

*Tied

BOSTON CHAPTER

The following is a review of the activities of the Boston chapter of the American Society for Steel Treating for the past four months. The October meeting was held at the plant of the New England Metallurgical corporation at South Boston. This plant which is a very up-to-date heat treating plant was in actual operation during the meeting. The speaker for this meeting was J. W. Black of the Geometric Tool Co., New Haven, Conn., who presented a paper entitled, "Hardening 25 Years Ago and Today." Following this paper, E. E. Roberts of the New England Metallurgical corporation made a few remarks and then presented some demonstrations which included the "Bellis Lava Process" and other interesting hardening methods with up-to-date equipment. There were 38 members and 66 guests present at this meeting.

The November meeting was held at the works of the Boston Consolidated Gas Co., at which time W. W. Cummings of the gas company presented a capable paper entitled "Gas—Its Manufacture and Application to Furnaces." At this meeting the Boston chapter had as guests W. S. Bidle and W. H.

Eisenman, officers of the National society. As a feature of this meeting there was a model gas making plant on exhibition and in operation. Prior to the meeting a dinner was served at which the Boston chapter members and friends were guests of the Boston Consolidated Gas Co. There were 44 members and 97 guests present at this meeting making a total of 141.

The December meeting which had been planned as one of the best of the year was held at the Massachusetts Institute of Technology. Unfortunately this part of the country had been swept by a blizzard the day and evening of the meeting which prevented many of the members from being present. The speaker, Dr. G. B. Waterhouse, professor of metallurgy of the Massachusetts Institute of Technology presented an interesting and capable paper entitled "Basic Open Hearth Steel." Following Dr. Waterhouse's presentation, Prof. I. H. Cowdrey explained in detail the different testing machines and apparatus that were on exhibition and in operation in his laboratory at the Massachusetts Institute of Technology. The attendance at this meeting was 40 members and 52 guests.

The January meeting was held at the Blake & Knowles plant of the Worthington Pump & Machinery Corp. Owing to the facilities at hand it was decided to make this a dinner meeting inasmuch as the company maintains a large cafeteria for their employes, the use of which was extended to the chapter. The members and guests were welcomed to the plant by George P. Aborn, works manager, who gave a short outline of the history of the Blake & Knowles plant from its infancy. A short talk was given by Otto Nonnenbruch, assistant chief oil engineer on the subject of "Diesel Engines."

The main speaker for this meeting was W. J. Kunkel of the forge department of the Blake & Knowles works who presented a capable paper on "Forging." This paper brought out many interesting points. An interesting and profitable discussion followed its presentation. After the meeting the forge department was in operation and was open for the inspection of the chapter members. Forgings were made, which included large 2000-pound crankshafts down to small tool forgings. These operations were of great interest to the visitors. The advantages of the autogenous cutting torch in forge practice was likewise demonstrated as well as the welding of monel metal with the acetylene flame and the babbitting of high efficiency bearings for heavy duty engine work. About 49 members and 141 guests were present for this meeting.

The February meeting of the chapter was held on the twentieth at the plant of the Edison Electric Illuminating Co. A get-together dinner prior to the meeting was served at 6:30 p. m. in the dining room of the Illuminating company's plant. Following this dinner E. F. Collins of the General Electric Co., Schenectady, presented a paper entitled "Electricity, and Its Application to Furnaces and Heat Treating of Steel." This paper brought out many valuable points of interest to steel treaters. Inasmuch as considerable interest in the use of large electrically-heated heat treating furnaces has been shown by heat treaters in general, the information which Mr. Collins brought out was very valuable and instructive.

The March meeting of the chapter will be held on the twenty-second at the Franklin Union. The speaker for this meeting will be Mr. Homerberg on the subject of "The Microscope as an Aid in the Solution of Practical Steel Problems."

CHICAGO CHAPTER

The report of the February meeting of the Chicago chapter appears on page 592.

CLEVELAND CHAPTER

The Cleveland chapter of the society held a meeting on Feb. 19 in the rooms of the Cleveland Engineering society, Hotel Winton. The program for this evening was a round table discussion on the subject of "gears," dealing with the various steels used in making gears; the forging and rolling of gears; the machining of gears, including a discussion of the condition of material for efficient machining; the heat treatment of gears including the carburizing and tempering; grinding of gears including methods of grinding and finally the inspection of gears, including examples of defects usually found. Each of these subjects were introduced by members of the chapter, who are specialists on the particular subjects and many valuable points were developed during this discussion. Due to the wide scope of the program as outlined, it was impossible to finish all of the topics and those topics which were not discussed will be presented at a meeting later in the year.

CINCINNATI CHAPTER

The regular February meeting of the Cincinnati chapter was held on the twelfth, in the Ohio Mechanics Institute at which time E. E. Thum of *Chemical and Metallurgical Engineering*, New York City presented an interesting paper entitled "Educating the Metallurgist and the Management." Mr. Thum brought out some very important points regarding the relationship between the metallurgist and the executive, pointing out that it is of prime importance that the metallurgist prove to the management that his department is an asset and not a liability. This meeting was very well attended.

LEHIGH VALLEY CHAPTER

The Lehigh Valley chapter of the society held a meeting on March 1 at the public library, North Sixth and Church streets, Easton, Pa. F. R. Palmer of the Carpenter Steel Co. presented a very enlightening paper entitled "Tool Steel." Mr. Palmer is a very capable metallurgist and has had considerable experience in the study of tool steels. He brought out many points of interest as evidenced by the valuable discussion which followed this paper.

MILWAUKEE CHAPTER

The Milwaukee chapter of the American Society for Steel Treating held its regular monthly meeting Wednesday evening, Feb. 21, 1923, in the Blatz hotel.

The chapter was fortunate in having as speakers for this meeting W. H. Eisenman, national society secretary, and Dr. P. D. Merica, metallurgist, with the International Nickel Co.

Mr. Eisenman gave an interesting talk on matters of interest to the local chapters and the national society, pointing out the aims and aspirations of the society in its work for the future and how the local chapters assist in carrying the work forward.

Dr. Merica presented a very capable paper entitled "Nickel and Its Uses

in Iron and Steel." He brought out many valuable points showing how nickel was playing a most important role in the alloy steel field. This paper was very interesting and developed a large amount of valuable and instructive discussion.

About 75 members and guests were present at the meeting, many of whom were present at the get-together dinner which was served at 6:45 p. m.

NEW HAVEN CHAPTER

The New Haven chapter of the American Society for Steel Treating held its regular February meeting Friday evening the sixteenth, in the assembly room of the New Haven Gas Light Co. The speaker for this evening was R. A. Cole, mechanical engineer of the Norton company of Worcester, Mass., who presented a paper entitled "Grinding." Mr. Cole displayed samples of grinding wheels and material to be ground as well as the results obtained through the use of various types and grades of wheels. These samples were of considerable interest to the membership. This paper brought out many valuable points and aroused considerable interesting discussion. Preceding the meeting the usual informal get-together dinner was served in the Cafe Mellone at 6 p. m.

The New Haven chapter of the American Society for Steel Treating held its March meeting Friday evening, the second, in the plant of the Geometric Tool Co. J. V. Emmons, national treasurer and metallurgist for the Cleveland Twist Drill Co., presented his paper entitled "Machinability of Tool Steels." This paper was illustrated with stereopticon slides and brought out many points of interest and value to the members. W. H. Eisenman, national secretary, was present and gave a short talk on the affairs of the society.

The heat treating department of the Geometric Tool Co. was in full operation and a practical demonstration and talk was given to the members. An informal get-together dinner was served at the Cafe Mellone preceding the meeting.

NEW YORK CHAPTER

The New York chapter of the society held its February meeting on the twenty-first in the assembly room of the Merchants Association of New York, on the ninth floor of the Woolworth building. Due to the fact that the speaker, J. V. Emmons, metallurgist for the Cleveland Twist Drill Co. was unable to be present his paper entitled "Machinability of Tool Steels" was presented by one of the members of the chapter. His paper was a very capable presentation of the effect of the structure of tool steels on their machinability and brought forth much favorable comment and discussion.

NORTH WEST CHAPTER

The North West chapter of the American Society for Steel Treating held its January meeting on the thirtieth in the Manufacturers' club rooms. This was an open meeting for the discussion of case hardening with particular reference to automobile parts for the Ideal Manufacturing Co. A discussion

was led by a committee appointed at the last meeting and a number of practical problems were presented and considered. This meeting proved to be highly instructive and of value to those who had the privilege of attending.

The North West chapter of the society held its regular monthly meeting on Monday evening, Feb. 19 in the Manufacturers' Club of Minnesota. The speaker for this evening was Dr. P. D. Merica, metallurgist of the International Nickel Co., who presented a paper entitled, "Nickel; Its Metallurgy and Industrial Applications." Dr. Merica has had wide experience in the metallurgy of both ferrous and nonferrous metals having formerly been with the United States Bureau of Standards. He has had extensive experience both in research and actual practice and spoke with authority upon the subject of nickel and nickel alloys. His paper brought out many valuable points of information and was of great interest to all of the members and guests who had the privilege of hearing him.

W. H. Eisenman, national secretary of the society was present at this meeting and addressed the membership on numerous society matters of interest to both the national body and the local chapters.

This meeting was a joint meeting with the members of the Minnesota section of the American Chemical society.

PHILADELPHIA CHAPTER

The Philadelphia chapter held its regular meeting on Friday evening, Feb. 23, in the Engineers' club, at which time A. W. F. Green, chief of laboratory, John Illingworth Steel Co. and chairman of the chapter presented an interesting paper entitled "Rolling Steel, Why, and What Happens." This paper was illustrated with stereopticon slides. Mr. Green outlined the progress that steel takes from the time it is cast into the ingot until it is ready for shipment, describing why it is necessary to roll steel and also what happens during this rolling operation.

J. V. Emmons, metallurgist of the Cleveland Twist Drill Co. and treasurer of the national society was scheduled to present a paper entitled "The Uses and Abuses of Twist Drills" but due to Mr. Emmons' illness he was unable to be present for this meeting; however, the motion pictures illustrating this subject were exhibited. They proved to be of considerable interest to all. The usual get-together dinner was served at 6:30 p. m. in the club dining rooms at which there was a very good attendance.

PITTSBURGH CHAPTER

The Pittsburgh chapter of the American Society for Steel Treating held its February meeting on the sixth in the William Penn hotel. E. E. Thum, associate editor of *Chemical & Metallurgical Engineering*, presented a very interesting paper entitled "Educating the Metallurgist and the Management." Mr. Thum had presented this paper before several of the other chapters and at each of these presentations his paper brought forth much valuable discussion and comment. The usual get-together dinner was served preceding the meeting.

ROCKFORD CHAPTER

The Rockford chapter of the American Society for Steel Treating held its January meeting on the nineteenth at the Hotel Nelson. S. M. Havens,

one of the directors of the national society, visited the chapter and gave a talk on matters of interest pertaining to the national society and the local chapters outlining concisely the aspirations of the national body for the future.

James P. Gill, metallurgist for the Vanadium-Alloys Steel Co. was the main speaker for this meeting and he presented a very capable paper entitled "The Tempering of Tool Steel." This paper was most universally applicable to the work that many of the members of the Rockford chapter are doing each day and as a result brought forth much interesting discussion following its presentation. Mr. Gill, who is a very capable metallurgist, handled this subject in a most capable manner.

SOUTH BEND CHAPTER

In the face of a blizzard and zero weather, the South Bend chapter held its February meeting on the fourteenth at the LaSalle hotel, attended by 71 members and guests. Dinner was served at 6:45 p. m. in the College Inn. Following the dinner, F. A. Hurcomb, manager of the M & S department of the Studebaker corporation, South Bend, read a paper on "Problems in the Machining of Heat Treated Stock." Discussion on this comprehensive paper is to be held in March.

The main speaker of the evening was E. E. Thum, associate editor of *Chemical and Metallurgical Engineering*, New York City. His subject was "Educating the Metallurgist and the Management." Mr. Thum scored the present technical university system for the apparent effort to crowd the technical and metallurgical courses with irrelevant subjects. He also strongly advocated the extension of the time of technical courses to five or six years. In regard to the "education of the management" Mr. Thum advised a program of advertising directed to the "men higher up" in order that credit due the metallurgist for reduction of production costs and improvement of methods should be brought to their attention, raising the standard of the technical man in the estimation of the management.

Among the guests present were W. P. Woodside and M. R. Kavanagh assistant production manager of the Studebaker corporation.

E. J. Janitzky, chief metallurgical engineer of Illinois Steel Co., South Chicago, will be the speaker on March 14, the paper to be illustrated with moving picture films of the practices of that firm in the production of steel.

SPRINGFIELD CHAPTER

The Springfield chapter held its January meeting on Friday evening the twenty-sixth in the Chamber of Commerce building. Members of the Springfield chapter were very fortunate in having with them James J. Curran, metallurgist of the Henry Souther Engineering Co., Hartford, Conn., who presented a very interesting and instructive paper entitled "Inspection and Heat Treatment of Steel." This paper was well illustrated with stereopticon slides. Mr. Curran brought out many valuable points and showed the importance of proper inspection of materials prior to their manufacture into components and their subsequent heat treatment. This meeting was very well attended and proved of value to all.

ST. LOUIS CHAPTER

The thirty-second meeting of the St. Louis chapter of the American Society for Steel Treating was held at 7:30 o'clock the evening of Feb. 19, 1923.

This meeting was held in the science lecture room of the David Rankin Jr., school of mechanical trades, and an opportunity was afforded the various members of the society to see, first hand, the physical testing of normal and heat treated steel.

R. J. Josehans, of the David Rankin school co-operated in extending to the society complete use of their facilities, and chairman C. B. Swander, having prepared suitable test specimens, illustrated their physical testing.

A universal testing machine was used where the members had an opportunity to see for themselves the automatic plotting of the elastic limit in testing the strength of steel, both normal and heat treated.

Explanation was given the members concerning the elastic limit, tensile strength, elongation and reduction area as applied to physical testing of steel.

Many comments were made and a lively discussion took place regarding the effect of heat treating on the physical properties of steel.

A vote of thanks was given Mr. Josehans for the extension of the facilities and likewise, Mr. Josehans expressed his interest in an endeavor include a heat treating department in the Rankin school.

There being no further business, the meeting adjourned to meet again March 12.

SYRACUSE CHAPTER

The Syracuse chapter of the American Society for Steel Treating held its regular monthly meeting on Feb. 13 at 9 p. m. in the Yates hotel, at which time R. J. Allen, first vice president of the National society presented a very interesting and capable paper entitled "Inspection and Testing of Steel." Mr. Allen, who is metallurgist for the Rolls-Royce Co. of America has had wide experience in the inspection and treatment of materials for automotive purposes. This paper was exceedingly interesting and brought forth much valuable discussion. There were about 75 members and guests present to welcome Mr. Allen and participate in the discussion which followed his paper.

TRI CITY CHAPTER

The Tri City chapter of the American Society for Steel Treating held its February meeting in the Davenport chamber of commerce on Thursday, Feb. 22, at which time Dr. P. D. Merica, presented a paper entitled "Nickel, Its Metallurgy and Uses." Dr. Merica, who is a metallurgist of national reputation and one of the leading authorities on nonferrous metals was formerly connected with the Bureau of Standards. He has a large fund of information to draw from and he presented a most capable paper dealing with nickel and nickel alloys. This paper brought out a very interesting dis-

cussion. W. H. Eisenman, national secretary of the society and S. M. Havens, national director of the society were present and each addressed the membership on matters of interest pertaining to the national society and the local chapters. This meeting was well attended.

The Tri City chapter of the American society for Steel Treating held its regular monthly meeting, Feb. 22, 1923. The meeting was called to order at 8 p. m. by the chairman. He announced the results of the Membership and Attendance contest as of Feb. 1, 1923, showing that the Tri City chapter was in fifth place. The membership was urged to attend all of the meetings and to bring in prospective members.

S. M. Havens, one of the directors of the national society, presented some facts on the business condition of the society. He showed that our society is in a very healthy financial position and is able to put aside money for reserve funds.

W. H. Eisenman, National secretary of the society, described the various activities of the society, especially the *TRANSACTIONS*, which have grown, both in quality and quantity, during the past year. He also told of the plans for the next annual convention which will be held at Pittsburgh in October.

Dr. Paul D. Merica, director of Research, International Nickel Co. was the speaker of the evening and his subject was "Nickel, Its Metallurgy and Uses." Dr. Merica traced the history of the development of the metallurgy of nickel and described in detail the three principal methods now in use for the refining of nickel.

The principal use of nickel is in the production of nickel steels, over 50 per cent of the total nickel production going into the manufacture of nickel steels. The two principal uses of nickel steels are for armor plate and for automotive parts. Dr. Merica gave a series of curves and data indicating the value of using nickel in steel. It was shown that the "Merit Index" of a nickel steel was considerably higher than that of a carbon steel of equal carbon content and compared favorably with other alloy steels.

Other uses for nickel are in coinage, where a nickel copper alloy is used; German-silver, which is a nickel-copper-zinc alloy; and cupro-nickel. About five per cent of the total nickel production is used for nickel-plating.

The meeting was then turned over to A. H. Putnam, who started a round table discussion on the subject of "Drop Dies." There was considerable discussion of the merits of alloy steel dies as against carbon steel dies; also the relative values of forged steel dies as against cast steel dies.

A rising vote of thanks was tendered Dr. Merica for the excellent presentation of his subject. The meeting adjourned at 10:45 p. m.

ADDRESSES OF NEW MEMBERS OF THE AMERICAN SOCIETY FOR
STEEL TREATING

EXPLANATION OF ABBREVIATIONS. M represents Member; A represents Associate Member; S represents Sustaining Member; J represents Junior Member, and Sb represents Subscribing Member. The figure following the letter shows the month in which the membership became effective.

NEW MEMBERS

- ADAMS, HARRY R., (A-1), 816 West Lake Street, Chicago, Ill.
 ALLEN, R. D., (M-1), M. & S. Dept. Studebaker Corp., Plant No. 2 South Bend, Ind.
 AMERICAN ENGINEERING CO., (S-1), Armingo Avenue & Cumberland Street, Philadelphia, Pa.
 APPS, WILLIAM, (M-2), c/o Autocar Co., Ardmore, Pa.
 ARVIDSON, G. ARTHUR, (Jr.-2), 1708 11th Street, Moline, Ill.
 BARNEY, M. H., (M-1), 212 Davis Street, Syracuse N. Y.
 BEEBE, S. C., (M-2), 90 Atkins Street, Meriden, Conn.
 BENSON, SIMON, (M-1), c/o Miehle P. P. & Mfg. Co., 14th & Roby Streets, Chicago, Ill.
 BLOCKS, EMIL C., (M-2), 1743 N. Troy Street, Chicago, Ill.
 BOCK, E. W., (A-1), 611 Majestic Bldg., Milwaukee, Wis.
 BOCKENFELD, LOUIS A., (Jr.-2), 1337 W. 7th Street, Davenport, Iowa.
 BURDETT, D. D., (M-2), 2974 Bershire Road, Cleveland Heights, Ohio.
 BURNETT, FREDERICK, (M-2), 43 Victoria Street, Toronto, Ont., Can.
 BUSCH, EDWARD A., (A-1), Box 81, Dayton, Ohio.
 CAMPBELL, T. A., (M-2), Remington Arms Co., Inc., Bridgeport, Conn.
 CINCINNATI BICKFORD TOOL CO., Oakley Cincinnati, Ohio. Att. of A. H. Tuechter, Pres.
 CONNER, CHAS. M., (A-1), 2224 Market Street, Philadelphia, Pa.
 CONSOLIDATED MACHINE TOOL CO. OF AMERICA, 2300 Vine Street, Philadelphia, Pa. Att. of E. J. Rollings.
 EADES, ENOS, (M-2), Rome Mfg. Co., Rome, N. Y.
 ELIASON, AUGUST, (M-1), 10463 127th Street, Richmond Hill, Long Island City, N. Y.
 ELLIOTT, WM. P., (Jr.-2), 129 S. Catherine Avenue, LaGrange, Ill.
 FAHRENWALD, F. A., (M-1), 1692 Glenmount Road, Cleveland, Ohio.
 FAULK, WM. M., (M-1), Yellow Sleeve Valve Engineering Co., E. Moline, Ill.
 FOWLER, F. W., (M-2), Barber-Colman Co., Rockford, Ill.
 FRASER, W. J., (M-2), 10 Sylvan Avenue, Toronto, Ont., Can.
 GALBRAITH, HARRY B., (M-2), 1214 10th Street, Rockford, Ill.
 GLAB, PETER, (M-1), 502 E. Jefferson Street, Syracuse, N. Y.
 HALL, L. NORRIS, (S-1) c/o L. Norris Hall, Inc., 940 Front Street, Philadelphia, Pa.
 HAMMERSLEY, JOHN, (M-8), 2130 Lakeview Avenue., Detroit, Mich.
 HARRITY, EUGENE E., (M-1), 107 Camp Avenue, Braddock, Pa.
 HARTEL, ANDREAS, III, (M-2), General Motors Research Corp., Dayton, Ohio.
 HASSAN, A. A. Jr., (M-2), Crucible Steel Co. of America, Harrison, N. J.
 HEARTLINE, E. H., (M-2), 315 12th Street, Moline, Ill.
 HINDE, WILFRID, (Jr.-1), Y. M. C. A., Moline, Ill.
 HISCOX, A. G. (M-10), Western Automatic Machine Co., Elyria, Ohio.
 HOBBS, D. B., (Jr.-11), 407 Thorn Street, Warren, Ohio.
 HOWAT, JOHN C., (M-2), R. D. Nuttal & Co., Pittsburgh, Pa.

- HOWELL, LEE A., (M-1), 623 Park Avenue, Syracuse, N. Y.
HAZELTON, R. T., (M-1), Cincinnati Shaper Co., Elm & Gerrard Streets, Cincinnati, Ohio.
HULL, D. R., (M-1), Anaconda American Brass Co., Ltd., Toronto, Ont., Can.
JENNINGS, W. H., Jr., (M-1), Brown-Lipe-Chapin Co., Syracuse, N. Y.
KINITE CO., (S-2), Milwaukee, Wis., Att. of Mr. Tatum, Mgr.
KLICK, V. L., (M-12), 121 Sterrett Avenue, Covington, Ky.
KOHLE, CLEMENT, (M-12), 3236 Columbus Avenue, Minneapolis, Minn.
LAFFIE, J. T., (M-2), 476 Capitol Avenue, Hartford, Conn.
LATHROP, D. W., (M-2), Canadian Atlas Crucible Steel Co., Welland, Ont., Can.
LATUS, HARRY J., (M-3), 865 9th Avenue, Milwaukee, Wis.
LAURENT, HOWARD, (M-2), Box 123, San Bernardino, Cal.
LODGE & SHIPLEY MACHINE TOOL CO., 355 Colerain Avenue, Cincinnati, Ohio. Att. of Mr. J. W. Carrell, V. P.
LOVEJOY, FREDERICK, (A-2), 128 Sidney Street, Cambridge, Mass.
LUCAS, H., (M-1), Apt. A-414 W. Washington, South Bend, Ind.
LUERSSEN, G. V., (M-1), Carpenter Steel Co., Reading, Pa.
MARSHALL, L. K., (Jr.-1), East Walpole, Mass.
MARTIN, H. E., (M-10), 870 Lathrop Avenue, Detroit, Mich.
MARTIN, J. F., (M-2), Bellevue Mfg. Co., Bellevue, Ohio.
MARINO, F. P., (M-2), 2437 Emerson Avenue, S., Minneapolis, Minn.
McALLISTER, ROBERT J., (M-1), 5621 Elliott Street, Philadelphia, Pa.
McCRUDDEN, F. R., (Jr.-1), 353 W. 2nd Street, Moorestown, N. J.
McKAIG, W. WALLACE, (Sub-1) Cumberland Steel Co., Cumberland, Md.
McPHEE, RALPH W., Henry Pels & Co., 90 W. Street, New York City.
MILLER, D. W., (M-2), 1517 Sherwin Avenue, Chicago, Ill.
NELSON, ANDRUS, (M-1), Deere & Mansur Co., Moline, Ill.
O'BRIEN, LAURENCE J., (Jr.-1) 719 E. Woodlawn Avenue, Philadelphia, Pa.
OLSEN, GUST Jr., (M-2), 1814 Farnum Street, Davenport, Iowa.
PARDIE, FRANK D., (M-1), 925 W. Onondaga Street, Syracuse, N. Y.
PRIESTER, CHAS. J., (M-1), Schoder & Lombard, 202 Centre Street, New York City.
RAUB, CLIFFORD A., (Jr.-2), 1423 Columbia Road, Washington, D. C.
REARDON, ARTHUR, S., (M-1), 67A, Enmore Road, Enmore, N. S. W. Australia.
ROCK ISLAND PLOW CO., (S-1), Rock Island, Ill. Att. of J. L. Irving.
SANFORD, C. G., (A-2), c/o Wm. Jessop & Sons Co., Inc., Boston, Mass.
SATTE, F. N., (A-2), 968 Eddy Road, Cleveland, Ohio.
SCHEID, A. J., (M-2), 707 Delaware Street, Minneapolis, Minn.
SCHWEITZER, CHAS., (M-2), 302 Hartson Street, Syracuse, N. Y.
SCHULTZ, C. H., (A-1), 4021 Northminster Street, N. S. Pittsburgh, Pa.
SMITH, HERBERT A., (M-2), c/o Autocar Co., Ardmore, Pa.
SMITH, JOHN G., (Jr.-1), 6701 N. 12th Street, Philadelphia, Pa.
SPRINGER, J. HALL, (M-12), 235 Bryant Avenue, Syracuse, N. Y.
SQUIRES, JOHN, (M-2), c/o Maxwell Motor Corp., Detroit, Mich.
STARINSKY, M. C., (M-2), 2825 Monroe Avenue, Cleveland, Ohio.
SUTPHEN, MARTIN, (M-1), 102 Pickett Street, Syracuse, N. Y.
THOMAS, E. L. (A-12), Consolidated Rendering Co., 40 N. Market Street, Boston, Mass.
THOMPSON, L., (M-1), 1600 S. State Street, Syracuse, N. Y.
THURSTON, P. R., (A-2), 1838 E. 101st Street, Cleveland, Ohio.
LIBRARY OF TOHOKU, (Sub-1) Imperial University, Sendai, Japan.

VERPOORTEN, PETER, (M-1), 318 Washington Street, Hoboken, N. J.
WEESNER, C. W., (M-2), Trumbull Steel Co., Warren, Ohio.
WESTERN ELECTRIC CO., (Sub-1), Hawthorne Station, Chicago, Ill.
WESTINGHOUSE ELECTRIC & MANUFACTURING CO., (Sub-9) Research
Laboratory, Ardmore Blvd., E. Pittsburgh, Pa.
WICKSTROM, A. H., (M-2), 718 Newell Street, Kenosha, Wis.
WILLIAMS-WHITE COMPANY (S-2), Moline, Ill.
WIRTEMBURG, G. H., (M-1), 181 Elm Street, Meriden, Conn.
ZIMMER, E. B., (M-1), 16623 West Park Avenue, Cleveland, Ohio.

CHANGES OF ADDRESS

ADELBERG, A. R., from Cyclops Steel Co., Broadway, New York City, to 1421
Arch St., Philadelphia, Pa.
BOYLE, JOHN D., from Newport Ave., Detroit, Mich., to Continental Motors
Corp., Muskegon, Mich.
CHERRY, R. M., from N. 50th St., Philadelphia, Pa., to General Electric Co.,
Witherspoon Bldg., Philadelphia, Pa.
CHRISTIAN, R. E., from Elmhurst Ave., Highland Park, Mich., to 341 Tuxedo
Ave., Highland Park, Mich.
COMSTOCK, G. D., from Stanley St., New Britain, Conn., to Suite E22-208
Farmington Ave., Hartford, Conn.
COOPER, CLARK JR., from Box 414, Millersburg, Pa., to 4130 Parkside Ave.,
Philadelphia, Pa.
GARDINER, F. E., from Crucible Steel Co. of America, 162-5 Richmond St., W.
Toronto, Canada, to Hiram Walker & Sons Metal Products Co., Ltd., Walker-
ville, Ont., Can.
HARTLEY, W. T., from Atlas Crucible Steel Co., 632 Washington Ave., Dunkirk,
N. Y., to 3882 W. 36th St., Cleveland, Ohio.
HOLMES, J. Q., from Nordyke & Mormon Co., Indianapolis, Ind., to 1031 N.
Pennsylvania Ave., Indianapolis, Ind.
JAYME, J. PHILLIP, from Labelle Works, Crucible Steel Co. of America, Pitts-
burgh, N. S. Pa., to Crucible Steel Co. of America, P. O. Box 11-Grand
Central Station, New York, N. Y.
LANE, H. M., from Owen Bldg., Detroit, Mich., to No. 333 State St., Detroit,
Mich., c/o H. M. Lane Co.
LARIME, E. J., from 5144 Belvidere Ave., Detroit, Mich., to 3071 Chalmers Ave.,
Detroit, Mich.
LASCHUK, S., from 904 W. Milwaukee Ave., Chicago, Ill., to 835 N. Robey St.,
Wicker Pk. Station, Chicago, Ill.
LEARMOUTH, W. J., from 8340 Dexter Blvd., Detroit, Mich., to 2035 Glynn
Court, Detroit, Mich.
LEE, I. H., from 1439 W. Grand Blvd., Detroit, Mich., to Studebaker Corp., De-
troit, Mich.
MACHOLL, E. A., from 7836 Lafayette, Detroit, Mich., to Standard Scale Co.,
Detroit, Mich.
MAIN, W. C., from 1985 E. 105th St., Cleveland, Ohio, to 10816 Columbia Ave.,
Cleveland, Ohio.
McANIFFE, H. F., from Holmes, Pa., Del. County, to 80 Lilac St., Buffalo, N. Y.
McGREGOR, HARRY, from 1124 Detroit St., Flint, Mich., to 806 Prospect St.,
Flint, Mich.
MEYERS, A. L., from R. K. Le Blond Machine Co., Edwards & Madison Rds.,
Cincinnati, Ohio, to Hill Clark Co., Chicago, Ill.
NORTHROP, H. B., from Diamond Chain Mfg. Co., Indianapolis, Ind., to 3730
Park Ave., Indianapolis, Ind.

- SHAW, G. M., from 1517 Continental Bldg., Baltimore, Md., to 4215 Wickford Rd., Roland Park, Baltimore, Md.
- SPITTAL, CHAS. W., from 819 Washington Ave., Dunkirk, N. Y., to 1353 Marlowe Ave., Lakewood, Ohio.
- SULLIVAN, L. J., from 309 First St., Keyport, N. J., to 25 Oak Ave., Myrtle Beach, Milford, Conn.
- TOPHAM, RICHARD A., from 12 Ray St., Schenectady, N. Y. to General Electric Co., Testing Laboratory, Lynn, Mass.
- VOIGT, J. S., from Plant 3, Timken Detroit Axle, Detroit, Mich., to 10037 Dalrymple, Detroit, Mich.
- WADLUND, A. P. R., from 30 Fairview St., Hartford, Conn., to 1087 Blvd., Hartford, Conn.
- WHITEHEAD, WM. A., from 3040 Warren Ave., Chicago, Ill., to 465 Commonwealth Ave., Boston, Mass.
- WRIGHT, F. G., from 1518 Euclid West, Detroit, Mich., to 396 Cortland Ave., Highland Park, Mich.

EMPLOYMENT SERVICE BUREAU

The employment service bureau is for all members of the Society. If you wish a position, your want ad will be printed at a charge of 50c each insertion in two issues of the Transactions.

This service is also for employers, whether you are members of the Society or not. If you will notify this department of the position you have open, your ad will be published at 50c per insertion in two issues of the Transactions. Fee must accompany copy.

Important Notice.

In addressing answers to advertisements on these pages, a stamped envelope containing your letter should be sent to AMERICAN SOCIETY FOR STEEL TREATING, 4600 Prospect Ave., Cleveland, O. It will be forwarded to the proper destination. It is necessary that letters should contain stamps for forwarding.

POSITIONS WANTED

WANTED—Position as Department Foreman in Heat Treating or Supervisor of Furnace Erection. Have had eight years experience with large firms and am anxious to be located with some firm where efforts to advance will be thoroughly appreciated. Address 12-25.

SUPERINTENDENT or GENERAL FOREMAN of heat treatment department. Experienced in all classes of carbon and high-speed tools and small forgings in quantity in coke, oil, gas or electric furnaces. Shore, Rockwell and Brinell hardness tests. Technical graduate. 15 years experience. Married. Address 12-5

POSITION WANTED IN HEAT TREATING LINE. Applicant has had six years experience as foreman in carburizing and can present the best of recommendations. No particular choice as to location, although prefer a position in the vicinity of Cleveland. Address 1-5.

METALLURGIST—desires position. Experienced and technically trained in chemical analysis, physical testing, microscopic work and heat treating of carbon and alloy steels. Address 11-5.

METALLURGIST—1916 Graduate with six years experience as chief chemist and chief metallurgist. Thoroughly familiar with ferrous and non-ferrous analysis, metallurgy, metallography and physical treatment. Has had also good production experience, having had charge at Steel melting and heat-treating departments. During past year has been metallurgist for a Government Arsenal, in charge of ferrous and non-ferrous research and testing. Available at once. Address 1-10.

CHEMIST and HEAT TREATER. Technical graduate. Experience in chemical, physical testing and heat treating of steels. Eastern location preferred. Reasonable salary. Address 2-1.

METALLURGIST—Desires Position—Nine years experience both in research and production in tool steel mills, standardization heat treatment of tool steels, metallography ferrous and non-ferrous metals, pyrometry, physical and chemical testing. Address 2-15

FOR SALE

FOR SALE—Two Wilson-Maeulen Tapalog Recorders, 4 point, 75-1800°F. Scale. Condition perfect, practically new. Can be purchased for less than one-half factory price. For further information write Box No. 2-5 A. S. S. T.

POSITIONS OPEN

GRADUATE METALLURGIST—Recent metallurgical graduate wanted for metallurgical department of a tool steel mill. Opportunity for experience and advancement. Western Pennsylvania. State in reply, education, age and experience, if any. Give three references. Address 3-10.

TOOL STEEL SALESMAN. New England States. Prefer one acquainted with the trade and now handling similar line. Do not apply unless you have had experience. This is one of the largest tool steel companies in the country, and affords a splendid opportunity for the right man. Address 3-5.

TECHNICAL GRADUATE with 2 years (or possibly less) experience. Preferably graduate in mechanical engineering with testing materials experience or training. Man would have variety of work such as mixing alloys, testing of materials and helping with miscellaneous experiments. Approximate salary \$150 per month. Location Cleveland. Address 2-25.

TECHNICAL GRADUATE to assist in experimental work in metallographic laboratory preferably with training in physical measurements. Metallurgical training or experience desirable but not absolutely necessary. Approximate salary \$150.00 per month. Location Cleveland. Address 2-20.

YOUNG MEN—High grade to travel through the great manufacturing and industrial districts to install, inspect and test electrical instruments and temperature controlling equipment; special consideration will be given to applicants having had experience in handling instruments, meters, gauges, recorders, controllers, etc.; educated men preferred; unusual chance for promotion; write, stating experience, education, age and salary desired. Address 12-20.

FOREMAN to take charge of hardening department in plant in east. Must be able to harden tools, such as broaches and reamers and carbon and high-speed steel as well as case hardening. Address 12-1.

WANTED A MAN—to take charge of heat treating department in an eastern city. An expert metallurgist is not a requirement for this position but a man who is familiar with carburizing and general heat treatment routine. Address 11-15.

WANTED—Metallurgist with mature experience in the melting and casting of nickel-chromium alloys. Permanent position offered by established concern. Erecting new plant shortly. Address 11-20.

Items of Interest

A NEW quenching device has recently been designed by the W. S. Rockwell company, which consists of a rectangular tank to be filled to any desired depth with circulating oil or water into which is mounted a partially submerged revolving drum. Heated metal parts of such size and shape as will permit tumbling about are then dropped into the submerged end of the rotating drum. The work is then automatically picked up in small batches by the internal thread of the rotating tank and conveyed through the quenching fluid as it is raised to the cone-shaped discharge spout. Naturally the device works best with a continuous flow of heated metal.

The Bureau of Foreign and Domestic Commerce and the Bureau of Mines have joined in producing a number of moving-picture films dealing with the methods of production and the manner in which machinery and apparatus of various sorts are utilized in different fields of activity.

They have been assisted in this work by various manufacturers throughout the country. These industrial object lessons, for such they really are, have aroused much interest and have awakened worthwhile reactions. This is not difficult to understand when we recall that with the vast majority of us the old saying, "Seeing is believing," is still paramount in carrying conviction.

In the preparation of these films, the Government experts have sought to spread both at home and abroad a knowledge of our methods of manufacture and of the applications of our products; and, not without reason, they have selected as subject matter for their films lines of industrial endeavor which would attract the attention of the greatest number of the populace. One of the latest of these films is entitled, "The Story of Compressed Air." It is the outcome of the joint efforts of the Department of Commerce, the United States Bureau of Mines and the Compressed Air Society. No pains have been spared to obtain reels which would bring home to any spectator the many helpful and valuable ways in which compressed air and pneumatic apparatus perform a multitude of essential services in our modern complex life. The pictures are both fascinating and instructive, and are a revelation of what the air compressor and air-driven tools and equipment are doing for us in a great many directions.

These films are available for exhibition. Further particulars regarding these films will be gladly furnished by the U. S. Department of Commerce, U. S. Bureau of Mines, or the Compressed Air Society, New York city.

The Atlas Steel Corp., Dunkirk, N. Y., announces the establishment of a research division of its metallurgical department. The research division is to be under the direction of Edgar C. Bain, who has been research metallurgist at the Cleveland Wire Division of the General Electric Co., and retains contact with them in a consulting capacity. Mr. Bain has done much pioneer work in the X-ray spectrographic study of the crystal structure of metals, and is the author of a number of papers on that subject. He will continue this phase of his researches in connection with other development work in special steels.

Frank Nickerson is no longer connected with the San Francisco office of the Midvale-Cambria Steel company but is now Southern California manager for the Bethlehem Steel Corporation with headquarters in the Washington building, Los Angeles.

The Dearborn Chemical Co. have recently issued a very complete 32 page illustrated book on the subject of "Applying Science to Inhibit Rust."

It treats the product NO-OX-ID as it has been successfully applied to the elimination of losses from rust and corrosion.

The general thought of the book is not new, but its treatment of rust as a disease of metal and its scientific remedying of this difficulty is new and very interesting.

The book states: "A true rust inhibitor must possess two characteristics: First, it must cover the surface properly to exclude external 'corrosive elements.' Second, it must quench the tendency of the surface of the metal to corrosion. Add to these characteristics, easy application, wide range of utility and moderate cost and you have the ideal rust preventive."

It covers various considerations in rust prevention thoroughly even to the point of showing direct application of the commodity in the numerous phases of the iron and steel industry. In export service, for pipe lines and tanks, in railway and marine service, and in ice and refrigerating plants. Numerous interesting instances of savings "from watch springs to battle ships" are quoted.

Copies of this book may be obtained from the Dearborn Chemical Company, 332 South Michigan avenue, Chicago.

The American Industrial Furnace Corporation, 10 Post Office Square, Boston, has moved to 422-428 Unity Building, 185 Devonshire St., that city.

The Hunter Crucible Steel company, a corporation organized under the laws of the State of Ohio, has acquired the plant and property formerly owned by the Electric Steel & Forge company, Cleveland, Ohio and will have a capitalization as follows:

Bonds to the extent of \$600,000; debenture notes, \$500,000; preferred stock, \$500,000; common stock, no par value, 123,000 shares. Of the debentures \$300,000 are being issued to provide working capital and \$150,000 worth of preferred stock in addition to bonds and common stock will be issued at once.

The Hunter Crucible Steel company produces a full line of hot rolled, electric and crucible furnace high speed, carbon and alloy tool steels, and automotive and special analysis steel products.

The property is located on a fifteen acre parcel of land at Grant Avenue and Cleveland Shore line railroad. The facilities are modern and with certain additions which are now being made will include crucible and electric melting furnaces, cogging and finishing hammers and presses, rolling mills, annealing and heat treating furnaces, cranes, laboratories, etc. The annual tonnage capacity of present facilities will be 12,000,000 pounds of hot rolled bars and 12,000 tons of high grade light part alloy locomotive and special forgings.

Keeping in step with recent developments in modern railroad locomotive design, the Hunter Crucible Steel company will also produce small part alloy steel locomotive forgings. This department of the company promises to develop a substantial volume of business. The operating officials of the company will be:

President—Arthur H. Hunter, formerly president of the Atlas Crucible Steel Co., and the Atlas Steel Corp., Dunkirk, N. Y.

First Vice President in Charge of Operation—Frank B. Lounsberry, formerly of the Halcomb Steel Co., Syracuse, N. Y., and since 1913 metallurgist engineer of the Atlas Crucible Steel Co., Dunkirk.

Second Vice President and Assistant to the President—Donald W. Wells, formerly vice president and general manager of the Electric Steel & Forge Co., Cleveland, O.

Treasurer—A. B. Smythe, president of A. B. Smythe & Co., Cleveland, O.

Secretary—L. H. Vinnedge, formerly auditor of the American Car & Foundry Co. Since 1915 vice president of the Atlas Crucible Steel Co.

Assistant Secretary—F. J. Beebe, formerly cost accountant of Atlas Crucible Steel Co.

Western Sales Agent—Frank P. Case, formerly sales manager of the Braeburn Steel Co., and recently of the Atlas Crucible Steel Co.

Eastern Sales Agent—L. M. Brown, formerly district manager of Cleveland and Pittsburgh districts for Atlas Crucible Steel Co.



Temperature

With the **F. and F. Optical Pyrometer** the temperature is measured by merely observing the object. It is accurate, simple, substantial and direct-reading.

(Write for Booklet)

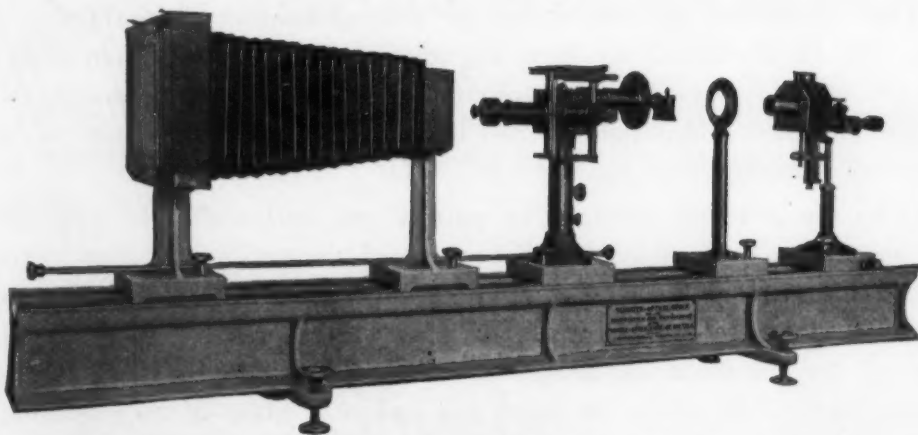
Hardness

The **S. M. Co. Brinell Machine** is the standard machine for measuring hardness of metals adopted by the leading concerns.

Pressure is applied quickly and uniformly; a special feature prevents leakage of the hydraulic fluid.



Micro-Structure



The **Scimatco Optical Bench** is the advanced outfit used by many of the foremost metallurgical firms for observing and photographing the micro structure of metals.

SCIENTIFIC MATERIALS COMPANY

"Everything for the Laboratory"

PITTSBURGH, PA.

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Assistant Sales Agent—Shirley G. Ellis, formerly in the production and sales department of the Carnegie Steel Co. and later New York district manager for the Atlas Crucible Steel Co.

In addition to the above heads, the company will have a complete trained and experienced operating and sales department.

Cleveland is a large market for the products of this company and its establishment marks a forward step in the industrial development of the city.

The waning petroleum supply of the country may be supplemented to great extent, according to Charles R. Fettke, associate professor of geology and mineralogy at Carnegie Institute of Technology, Pittsburgh, by taking the enormous quantities of bituminous coal now being burned in the raw state for steam raising purposes and domestic use, and subjecting it to low-temperature carbonization. This process, he says, will produce a fuel that is in many respects superior to raw coal, the smoke nuisance of cities will be abated, and valuable by-products will be recovered, which will aid greatly in affecting a petroleum supply that is being rapidly depleted.

Professor Fettke emphasizes the warning in his report, that the unmined reserves of petroleum are being so rapidly reduced that one of the problems that will have to be faced within the next decade or two will be to find substitutes in continually growing amounts for the products now obtained from it.

"The distillation of oils from oil shales, another important source of supply, will be restricted to those regions where enormous quantities of the shales are found," says Professor Fettke. "Where bituminous coal is found in larger quantities than shale, it will be more economical to confine the business of oil distillation to coal.

"With the growing shortage of natural gas and anthracite coal and their consequent increase in price, other sources of domestic fuel must come more and more into use. One of these will undoubtedly be low-temperature coke. The low-temperature carbonization of coal in this respect will have the advantage of the oil shale industry. It will yield a valuable fuel as a residue while the spent shale from the latter not only has little or no economic value, but means will have to be provided for its disposal."

Lewis J. Firth, president of the Firth-Sterling Steel Co., Pittsburgh, has returned to the United States after an absence of several months. Mr. Firth will make his headquarters at the plant in McKeesport, Pa., and in Pittsburgh for several months.

SIMONDS STEEL

CRUCIBLE ——— ELECTRIC

**High Speed Steel
Magnet Steels
Chrome Ball and Bearing Steels
Carbon and Alloy Tool Steels
Special Steels**

TO know that the steel ordered today will duplicate in every respect that which gave unusual efficiency six months ago, is a satisfaction to the consumer made possible only by years of experience in making **QUALITY Steels UNIFORM** at all times.

SIMONDS STEEL in your hardening room allows you fixed temperatures in heat treating and eliminates those costly "trouble days".

**We Develop Steels Required
For Particular Hard Usage**

Bars

Sheets

Billets

**SIMONDS SAW AND STEEL CO.
STEEL MILLS
LOCKPORT, N. Y.**

Edgar T. Ward Sons Co., Distributors

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Announcement has been made of the tercentenary of the founding of the city of Gothenburg, Sweden, at which time a Jubilee Exhibition will be held. This celebration will take place between the dates of May 8th and Sept. 30th, 1923. During this period about forty Swedish steel and iron mills will exhibit specimens of everything they produce. This exposition will be one of the largest and most complete ever held in northern Europe and it is anticipated that hundreds of manufacturers from America will likewise exhibit materials made in America. Complete information in reference to this event can be obtained by addressing the Swedish Travel Bureau, 21-24 State Street, New York City.

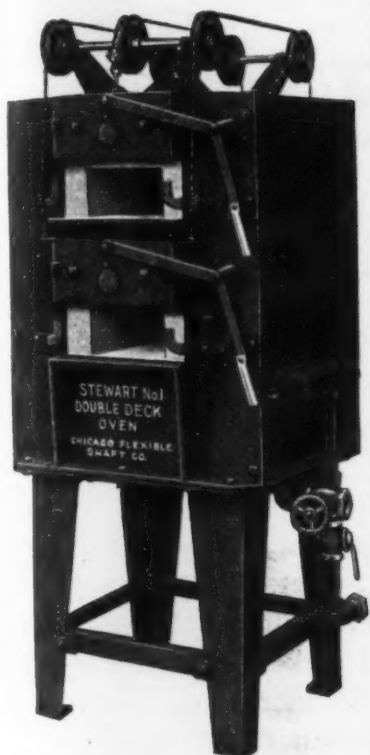
W. F. Furman has been appointed district manager for the Cutler Steel Company of Pittsburgh and will make his headquarters at 50 Church Street, New York City. Mr Furman was for many years with the American Locomotive Company and more recently the eastern representative of the Le Moyne Steel Company of Pittsburgh.

Sam Heppenstall has been elected chairman of the board of directors of Heppenstall Forge & Knife Co., Pittsburgh, and C. W. Heppenstall has been elected president to succeed him. S. B. Heppenstall continues as vice president and Floyd Rose as secretary.

Karl M. Knapp, who has been in charge of the Pittsburgh district for the past three years, has been made district manager of the combined Cleveland and Pittsburgh territories of the Cyclops Steel Co., Cleveland. Offices will be located at 609 Chamber of Commerce building, Pittsburgh, and 1224 Oregon avenue, Cleveland.

A. W. Copeland, president of the Detroit Gear & Machine Co., has been elected to fill the vacancy caused by the death of John B. Foote of the American Gear Manufacturer's association.

The Carbon Steel Co., Pittsburgh, will be dissolved and its assets sold as a result of a vote of the stockholders. The plant, officials say is



**Stewart Double Deck
Furnace for High Speed
and Carbon Steel**

Eliminates the necessity of additional equipment if you have room for only one furnace.

The pieces are thoroughly preheated in the upper chamber before being removed to the lower chamber for the high heat.

Its advantages—

Less fuel consumption: Upper chamber heated by waste gases from lower chamber. Carbofrax floor and supports in lower chamber—high heat conductivity.

Less floor space

Less air supply

More and better production

Made in five standard sizes—special sizes to order.

Proper Hardening of High Speed Steel

Experience has taught us that it is just as harmful to put a piece of cold high speed steel into a high heat chamber without preheating as to quench it suddenly in cold water from a high heat.

It is imperative to preheat all parts to at least 1600° F. before placing in the finishing heat of 2250°, as the sudden shock of the intense temperature of the high speed furnace frequently causes cracks—cracks which do not show up until the tool is put into use.

For the preheating operation there are Stewart Oven Furnaces of various capacities—or the Stewart Double Deck Furnace (illustrated at left), which is adapted to both preheating and high speed steel heats.

*Write for our new bulletin on
high speed steel furnaces*

Chicago Flexible Shaft Company

1144 South Central Ave., Chicago

16 Reade St., New York
Wainwright Bldg., St. Louis
608 Kerr Bldg., Detroit
79 Milk St., Boston
305 Merchants Bank Bldg., Indianapolis
768 Mission St., San Francisco
921 Granite Bldg., Rochester, N. Y.
331 Fourth Avenue, Pittsburgh, Pa.
940 North Front St., Philadelphia, Pa.
1738 19th St., Milwaukee, Wis.

Canadian office and factory, 349 Carlaw Ave., Toronto, Can.

Stewart Vertical Muffle Furnace

For use where products of combustion must be kept from contact with the work, when used for heat treating long pieces apt to be distorted when laid on oven floor.

Recommended for broaches, reamers, hobs, cutters, drills and similar articles.

Three standard sizes.



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out of date and can no longer be operated at a profit. The Carbon Steel Co. manufactures principally alloy steel bars and billets. It has been in business about 40 years. The company was incorporated under the laws of West Virginia and has a capitalization of \$5,000,000. Attorney J. B. Orr, secretary and treasurer of the company, declares that liquidation will take place slowly. If feasible, the plant will be disposed of as a whole, he said. The company has six open-hearth furnaces and one electric furnace with an annual capacity of 150,000 tons of ingots. The equipment provides for the production of plates, sheets and bars.

The general sales offices of the Cutler Steel Company, which has been maintained for the past two years at 50 Church Street, New York City, has been transferred to the Bowman Building, Pittsburgh, Pa. W. H. Waddington, vice president in charge of sales, will make his headquarters at the Pittsburgh address. The Cutler Steel Company manufactures "Duraloy" the original chrome iron,—a metal which resists oxidation, corrosion and abrasion.

Co-operating with the department of commerce and the bureau of mines, the Interstate Iron & Steel Co. has recently completed a film of three reels picturing "The Story of Alloy Steel." The film is loaned free of charge by making application to either the department of commerce or the bureau of mines and will be included in the government's film series. "The Story of Alloy Steel" visually describes the manufacturing processes involved in the production of steel from the point in the process where there is a divergence in the practice as compared with the process employed in producing ordinary steel.

P. D. Brown has been appointed general sales manager of the Poldi Steel Corp. of America with headquarters at 115 Broadway, New York, succeeding George H. Grundy, resigned. For some time past Mr. Brown has been acting in the capacity of district sales manager for the corporation at Baltimore, Md., and for many years previous to that he was manager of the Baltimore branch of the Crucible Steel Co. of America. The Poldi corporation also announces the appointment of L. C. Gosselin assistant general sales manager.

THE OIL AGE

The Literary Digest, Atlantic Monthly, and New York Times have recently published some very interesting facts and comment with respect to oil as a world problem.

Unquestionably the international scramble for productive oil fields presents political complications of a very important and delicate nature.

While it is the purpose of this copy to discuss oil in its commercial aspects,—that is, industrially and economically,—it is undoubtedly true that there is grave necessity for statesmen and business men to work in an intelligent spirit of co-operation in obtaining and conserving an adequate supply.

Economically and industrially the service rendered to humanity by oil is such that we live in what can be termed, in very fact, the Oil Age.

It would be tiresome to enumerate the various uses to which oil is put in its crude, refined and by-product states. Its light and heat giving, and heat treating and power giving qualities make it the greatest of all international prizes.

The rapidity with which the supply in some fields is exhausted makes its conservation loom large as a matter of business economics.

There is enormous waste going on in the plant life of the country through the use of home made or unscientifically made heat treating devices burning oil as fuel.

Such equipment creates enormous waste because of extravagant use of fuel and because of the poor quality of products turned out.

Scientifically made equipment saves fuel and creates economy and efficiency in amount and kind of product.

The MAHRVEL Blue Line of TORCHES, FORGES and FURNACES meets the situation. It is the most complete and dependable line of Oil Burning Equipment manufactured by any one corporation anywhere.

This company's products are the result of inventive genius plus years of skilled engineering development.

The use of a MAHRVEL unit means the buying of more of those units and other products made by the company.

Give us a trial order

Mahr Manufacturing Company

Minneapolis, Minn., U. S. A.

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It has been reported that the Inland Engineering Co., recently incorporated in Chicago will manufacture manganese and chromium steel castings. The president of this new company, Walter S. McKee has been in this industry for nearly 20 years, having formerly been vice president and director of the American Manganese Steel Co. The vice president, Edward S. Black, has had wide experience in designing special castings for steel mills, blast furnaces etc. E. C. Bauer and J. W. Plant each of whom are vice presidents of the new company have had many years of selling experience along the line of steel castings. Alfred Exton is chief engineer and Claud Rorabeck is consulting engineer. Each of these men have had years of experience in this line of endeavor.

The capacity of the Witherow Steel company, Pittsburgh, will be more than doubled as a result of improvements now being planned. The company has merged with the River Front Land company under the name of the Witherow Steel company. The capital stock has been increased to \$2,800,000 preferred and 10,000 shares of common, no par value.

The Heat Treating Equipment Co., 79 Milk St., Boston, Mass., has been appointed exclusive representative throughout the United States for the re-sale of the Brearley Sentinel Pyrometer manufactured by the Amalgams Co., Sheffield, England. G. C. Davis, of the Heat Treating Equipment Co. announces that his company is prepared to ship this type of equipment from stock at Boston.

Henry T. Chandler formerly associated with C. Harold Wills & Co., as metallurgical engineer has become associated with the Vanadium Corp. of America, Detroit office.

Mr. Chandler received his technical training at the University of California and the Massachusetts Institute of Technology, and later completed his education in Paris and Switzerland.

A general conference was called by Dr. John E. Monger, state director of health, to be held Feb. 13 at the Engineers club, Southern hotel, Columbus, O. The purpose of this meeting was to consider safety regulations for gas heating devices. Engineers and manufacturers interested in gas heating devices were invited to be present.

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